



Phosphorus, agriculture & organic waste: a Danish P balance

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7th International Phosphorus Workshop, IPW7

Uppsala, Sweden, 9-13 September 2013

Programme and Book of Abstracts

Published by

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CONTENTS

4	Organising Committee
4	Scientific Advisory Committee
5	Foreword
6	General Information
10	Programme at a glance
11	Programme
16	Scientific advisory committee
19	Introductory keynote presentation
23	Theme 1 P management in a changing world
31	Theme 2 Transport pathways of P from soil to water
37	Theme 3 Monitoring, modeling and risk assessment at different scales
45	Theme 4 The importance of manure and cropping systems for P management
53	Theme 5 Identification of appropriate mitigation measures for reduction of P losses
61	Theme 6 Implementation of mitigation strategies to reduce P losses
69	Poster Presentations
162	Index
	Map of Uppsala

ORGANISING COMMITTEE

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Paul Withers	(Bangor University, UK)

FOREWORD

As organisers of the 7th International Phosphorus Workshop – also known as IPW7 – it is our great pleasure to welcome you to Uppsala on 9-13 September 2013. The workshop is being organised jointly by the Departments of Soil & Environment and Aquatic Sciences & Assessment at the Swedish University of Agricultural Sciences, the Swedish Board of Agriculture, and the Department of Physics, Chemistry and Biology at Linköping University. We are very excited to report that there will be many delegates at this meeting. More than 130 participants from about 25 countries will attend and contribute to the different sessions, including the workshop discussions. We are dedicated to doing our best to making IPW7 memorable for all of you and we hope that the days in Uppsala will provide participants with inspiration for future research and practical applications.

With the help of scientific research in close cooperation with practitioners (regulators, advisors, farmers etc.), it may be possible to combine safe and profitable food production with good environmental quality and sustainable use of natural resources. The IPW7 meeting will provide information about phosphorus (P) management in a changing world, including the importance of manure and cropping systems, identification and implementation of mitigation strategies to reduce P losses, transport pathways of P from soil to water, and monitoring, modelling and risk assessment at different scales. We are proud to present this volume of abstracts, which contains more than 120 abstracts, covering a wide range of topics within the themes of IPW7. Active participation, intense discussions, new insights and new contacts are some of the features that we expect to characterise IPW7. We also hope that participants at this meeting will ensure that IPW7 forms an important link in the chain of IPW meetings that started in Wexford, Ireland, in 1995.

On behalf of the organisers, we would like to express our gratitude to all those who have contributed to IPW7. Many people have enthusiastically participated in the planning and preparation of these five days in Uppsala, including people supporting the Organising Committee, members of the Scientific Advisory Committee, and Johanna Thyselius Nilsson and her colleagues at the Conference Secretariat. Thank you all for your positive attitude and fantastic support! Mary McAfee checked the language in many of the submitted abstracts. Thank you for your fantastic help and fast response! Financial support was received from the Swedish Research Council Formas, Yara, the Swedish Plant Nutrition Foundation, Uppsala Water Center, the Faculty of Natural Resources and Agricultural Sciences (SLU) and Nordkalk Corporation, to whom we express our sincere thanks. Finally, special thanks to you, the delegates, for supplying the input needed for a successful scientific meeting through high quality presentations during oral and poster sessions. We wholeheartedly welcome you and hope that you find IPW7 as successful and rewarding as we envision it to be.

Lars Bergström, Barbro Ulén, Helena Aronsson, Faruk Djodjic,
Karin Tonderski, Katarina Börling

THE ORGANISING COMMITTEE FOR IPW7

GENERAL INFORMATION

Conference venue

The conference takes place at Loftet (Plenary, parallel, and poster sessions) and in Undervisningshuset (Parallel sessions) at SLU, Ultuna Campus, in Uppsala, Sweden.

Address Loftet: Duhrevägen 8 ▪ *Address: Undervisningshuset:* Almas allé 10

Conference rooms:

Loftets hörsal – Plenary and parallel sessions

Room B, C, D, E, G - Parallel sessions

Loftets stora sal – Poster sessions

Conference secretariat opening hours

Loftet, SLU Ultuna Campus:

Monday September 9	14:00-16:30
Tuesday September 10	08:00-17.30 (During breaks)
Wednesday September 11	08:00-17.30 (During breaks)
Thursday September 12	Closed (Excursion all day)
Friday September 13	08.00-13.00

Name badge

Your name badge is your admission to the scientific sessions as well as to coffee and lunches. It should be worn at all times at the conference venue.

Internet access

Wireless Internet access is available at the venue.

Coffee

Coffee will be served at Loftet (the main venue).

Lunches

Lunches will be served in Ultunarestaurangen. Your name badge is your ticket. If you have any dietary requests that you have informed the organisers about in your registration, please inform the staff in the restaurant.

Mounting and dismounting of posters

Posters are expected to be displayed during the whole conference. The maximum poster size is 140 cm (height) x 100 cm (width). The posters should be mounted with pins. Pins will be available in the poster room.

Mounting: From 14:00 on Monday September 9

Dismounting: Before 13.30 on Friday September 13

The organisers accept no liability for posters not dismounted by 13.30 on Friday September 13.

Social events

Welcome reception, Monday September 9 at 16.30

We meet together outdoors for a light mingle buffet and something to drink.

Venue: Kunskapsträdgården at Ultuna Campus

Guided city walk, Tuesday September 10 at 18.15

A city walk for about an hour to see the historical attractions of Uppsala.

For example: Uppsala Castle, the Dome, the University main building and the University Museum Gustavianum.

Start point: The Dome/Domkyrkan. (Two of the shuttle buses from Ultuna will have drop off at The Dome/Domkyrkan)

Conference Dinner at Norrlands Nation, Wednesday, September 11 at 19.00

The IPW conference dinner will take place at Norrlands Nation

(Address: Västra Ågatan 14).

If you have registered for the dinner you have received a ticket at registration. If you have not registered but wish to attend, please contact the conference secretariat for available tickets.

OTHER PRACTICAL INFORMATION

Conference hotels

Akademihotellet, address: Övre Slottsgatan 5

Tel: +46 18 15 51 90, e-mail: info@akademihotellet.se

Best Western Hotel Svava, address: Bangårdsgatan 24

Tel: +46 18 13 00 30. e-mail: info@hotelsvava.se

Grand Hotel Hörnan, address: Bangårdsgatan 1

Tel: +46 18 13 93 80, e-mail: info@grandhotellhornan.com

Park in by Radisson Uppsala, address: Storgatan 30

Tel: +46 18 68 11 00, e-mail: info.uppsala@rezidorparkinn.com

Sunnersta Herrgård, address: Sunnerstavägen 24

Tel: +46 18 32 42 20, info@sunnerstaherrgard.se

Money exchange, currency

Swedish Krona (SEK) is the official currency in Sweden. One exchange office is located at Fyristorg 8. There are plenty of cash dispensers in Uppsala. Major international credit cards are accepted in most hotels, shops and restaurants.

Shopping in Uppsala

Most stores in Uppsala are open 10:00-19:00 on weekdays and 10:00-17:00 on Saturdays. Some stores are open on Sundays as well. Grocery stores usually have longer opening hours.

Bus transfers

The IPW 7 workshop will provide free bus transfer to and from the venue as follows:

Bus stop in Uppsala city: Uppsala Konsert & Kongress (UKK) at Storgatan.

Bus stop at Ultuna: Next to the Ultuna restaurant.

Monday September 9

Buses depart at 18.00 from Campus Ultuna to UKK, via Sunnersta Herrgård

Tuesday September 10

Buses depart at 08.00 from UKK to Campus Ultuna, via Sunnersta Herrgård

Buses depart at 18.00 from Campus Ultuna to UKK, via The Dome/Domkyrkan for those registered for the Guided City Walk

Wednesday September 11

Buses depart at 08.00 from UKK to Campus Ultuna, via Sunnersta Herrgård

Buses depart at 17.45 from Campus Ultuna to UKK, via Sunnersta Herrgård

Thursday September 12

Excursion A: Field experimental facilities around Uppsala and Lövsta animal husbandry research center. Departure Sunnersta Herrgård: 07.30, UKK: 08.00. Return Sunnersta Herrgård: 16.45, return UKK: approximately 17.00.

Excursion B: Wastewater treatment along the coast of the Baltic Sea –different ways to meet high demands of P and N reductions. Departure Sunnersta Herrgård: 07.30, UKK: 08.00. Return UKK: 17.30, Sunnersta: 17:45.

Excursion C: Boat trip on the Baltic Sea. Departure UKK: 07.30. Return UKK: approximately 18.30.

Excursion D: Monitoring and research facilities around Lake Mälaren – a trip across scales. Departure Sunnersta Herrgård: 07.30, UKK: 08.00. Return UKK: approximately 19.30, return Sunnersta Herrgård: 19.45

Participants in excursion B, C and D have the opportunity to stay in Stockholm after the excursion. You are then responsible for your own transportation back to Uppsala.

Friday September 13

Buses depart at 08.00 from UKK to Campus Ultuna, via Sunnersta Herrgård

Buses depart at 13.10 from Campus Ultuna to UKK

Local bus between the City centre and the Venue

Bus no 12, 20, 110, 115 from “Centralstation” to “Centrala Ultuna”. Ticket options:

- 1) Single tickets can be bought from a machine at “Centralstation”, SEK 25/ticket.
- 2) A single ticket can also be purchased from the bus driver (credit card only), SEK 30/ticket.

Travelling between Stockholm Arlanda International Airport and Uppsala

Taxi

You can pre-book a taxi at (+46) 123 456 or at www.taxikurir.se. The price to get to Stockholm Arlanda International Airport is about SEK 460 (50 Euro).

Bus

Bus 801 runs between Uppsala Central Station and Arlanda 1-2 times/hour the whole day and night. The journey takes about 45 minutes and costs 100 SEK (10 Euro). You can buy your ticket by credit card through a ticket machine in terminal 2, 4 and 5 at Arlanda airport and at Uppsala Central station. You can also pay by credit card on the bus.

Train

Trains leave Uppsala Central Station for Arlanda Airport 1-3 times/hour from 5:00 until 23:00. The journey takes 15-20 minutes and costs 95-140 SEK (10-14 Euro) if purchased in advance at Uppsala Central Station.

Tourist information in Uppsala

Address: Kungsgatan 59, Uppsala

<http://www.destinationuppsala.se/en/>, info@destinationuppsala.se

Emergency calls

You should call 112 if anything occurs which means that an ambulance, the police or the fire brigade needs to be called out. 112 is a special emergency number you can call wherever you may find yourself, from a fixed or a mobile telephone.

International calls

Dial 00 + country code + area code + phone number. For example to Spain 0034, to Norway 0047.

Electricity

In Sweden the electrical voltage used is 220/230V.

Pharmacy

There are several pharmacies in Uppsala. Look for 'Apotek'.

Medical services

Uppsala University Hospital, Akademiska sjukhuset, is located in central Uppsala.

Telephone: +46 18 611 0000. The emergency room is called "Akuten" in Swedish.

Smoking

Smoking is not allowed in the conference venues, or in any other public indoor establishments such as restaurants, bars, etc.

Conference secretariat

Academic Conferences – SLU and Uppsala University in cooperation

Office contact details during office hours (8:00-16:00 local time)

Tel: +46 (0)18 67 10 34, +46 18 67 10 03

E-mail: ipw7@slu.se

PROGRAMME AT A GLANCE

	Monday September 9	Tuesday September 10	Wednesday September 11	Thursday September 12	Friday September 13
Morning		Presentations	Presentations	Excursion	Presentations
Lunch		Lunch	Lunch		Lunch to go
Afternoon	Registration, Opening and Welcome reception	Workshops	Workshops		
Evening		Guided City Walk	Conference Dinner, Norrlands nation		

PROGRAMME

Monday 9 September

- 14:00–14:45 Registration and coffee
- 14:45–16:30 Opening
Introduction
Keynote: Andrew Sharpley
Future agriculture with minimized phosphorus losses to waters
- 16:30–18.00 Welcome Reception at SLU Garden / Kunskasträdgården

Tuesday 10 September

- 08:30–09:00 Poster session
- 09:00–09:30 **Theme 1: Phosphorus management in a changing world**
Keynote: Oscar Schoumans, F. Bouraoui, C. Kabbe,
K. van Dijk, O. Oenema
Phosphorus management in a changing world – coping with the effects of an increasing human population, resource scarcity and climate change
- 09:30–10:15 M. Fitter, J. Crossman, P.G. Whitehead
Climate proofing phosphorus management: a model based assessment of tradeoffs and uncertainties
- Marc Stutter, C. Shand, T. George, M. Blackwell, L. Dixon, R. Bol,
R. MacKay, A. Richardson, L. Condon, B. Turner, P. Haygarth
Are dual goals of increasing P availability to crops and increasing soil C mutually exclusive?
- Paul Withers, R. Sylvester-Bradley, A.C. Edwards, D.L. Jones
Why do we still sprinkle salts on the soil: phosphorus?
- 10:15–10:45 Coffee

10:45–11:15 **Theme 2: Transport pathways of Phosphorus from soil to water**

Keynote: Christian Stamm

Transport pathways of P from soil to water

11:15–12:00 Barbara Cade-Menun, S. Baker-Ismail, D. Barrett, G. Bell, Y. Fouli, K. Hodder, D.W. McMartin, C. Perez-Valdiva, K. Wu

Phosphorus forms and concentrations in snow melt runoff from Saskatchewan cropland and pasture

Helen Jarvie, A.N. Sharpley, J.V. Brahana, T. Simmons, A.J. Lawlor

Multi-element hydrochemical signatures to explore pathways and attenuation of phosphorus in karst terrain

Per-Erik Mellander, A.R. Melland, P. Jordan, P.N.C. Murphy, G. Shuttle

Catchment integrated phosphorus transfer pathways within the agricultural landscape

Pause

12:15–12:45 **Theme 3: Monitoring, modeling and risk assessment at different scales**

Keynote: Marianne Bechmann

Monitoring, modelling and risk assessment at different scales – targeting critical source areas

12:45–13:30 Faruk Djodjic

Integrating scales –distributed, high-resolution modeling of erosion and phosphorus losses

Caroline Van der Salm, I.G.A.M. Noij, W.M. Appels, H.T.L. Massop

Combining modeling and direct measurement to quantify nutrient surface runoff from flat fields

Carl Bolster, P. Vadas

Incorporating uncertainty analysis in a field-scale P loss model

13:30–15:00 Lunch + poster session

15:00–17:30 Workshops in thematic groups

18:15 Guided City Walk. Start point: The Dome/Domkyrkan

Wednesday 11 September

08:30–09:00 Poster session

09:00–09:30 **Theme 4: The importance of manure and cropping systems for Phosphorus management**

Keynote: Paul Withers, B. Ulén, H. Aronsson, P. Pavinato

The importance of manure and cropping system for phosphorus management – how do we reach long-term sustainability?

09:30–10:15 Yanan Tong

Changes of soil fertility parameters and nutrient balance in the irrigated area of southern loess plateau, China

Thijs Vanden Nest, B. Vandecasteele, G. Ruyschaert, T. D'Hose, M. Cougnon, R. Merckx, D. Reheul

Long-term effect of various fertilizing strategies on soil organic carbon, crop yield, soil P availability and potential P leaching

Dalel Abdi, B.J. Cade-Menun, N. Ziadi, L.E. Parent

Long term impact of tillage practices and P fertilization on soil P forms as determined by ³¹P-NMR

10:15–10:45 Coffee

10:45–11:15 **Theme 5: Identification of appropriate mitigation measures for reduction of Phosphorus losses**

Keynote: Risto Uusitalo, A. Näreänen, K. Rasa, A. Klimeski, E. Turtola

Identification of appropriate mitigation measures for reduction of P losses – are chemical methods a viable option to curb P losses during the transport phase?

11:15–12:00 Saara Kirjalainen (née Hirvonen), P. Ekholm, E. Jaakkola, P. Valkama, M. Kiirikki, K. Lahti, S. Luomanperä

Gypsum amendment of soils as a mitigation measure for reduction of phosphorus losses in an agricultural catchment – effects and duration

Leo Condrón, E.M. Harris, T.J. Clough

Impact of biochar amendment on phosphorus retention by riparian soil

Gryly Lyngsie, C.J. Penn, O.K. Borggaard, H.C.B. Hansen

Sorbent for phosphate removal from agricultural drainage water

Pause

- 12:15–12:45 **Theme 6: Implementation of mitigation strategies to reduce Phosphorus losses**
 Keynote: Andrew N. Sharpley, P.J. Kleinman, P.J.A. Withers, L. Bergström
Implementation of agricultural phosphorus management to protect water quality – lessons under voluntary and regulated adoption
- 12:45–13:30 Douglas Smith
The effects of conservation practices on phosphorus losses from row crop agriculture in the St Joseph river watershed, USA
- Jehangir Bhadha, S. Daroub, T. Lang
Implementation and verification of BMPs to reduce farm P loads: A long-term collaborative effort
- Katarina Kyllmar, S. Andersson, A. Aurell-Svensson, F. Djodjic, E. Ekre, J. Gustafsson, A. Heeb, J. Malgeryd, L. Stjernman Forsberg, B. Ulén
Identifying P loss risk and appropriate mitigation measures at farm level in co-operation between farmers and agricultural advisers
- 13:30–15:00 Lunch and poster session
- 15:00–17:30 Workshops in thematic groups
- 19:00 Conference Dinner in central Uppsala



Thursday 12 September

07:30–18:00 Excursion: Parallel field trips, A-D

Friday 13 September

08:30–09:00 Astrid Oberson, C. Bonvin, S.A. Nanzer, F. Tamburini, B. Etter, K.M. Udert, E. Frossard **(Theme 1)**

Plant uptake of phosphorus recycled from human urine and sewage sludge ashes

Dries Verheyen, N. Van Gaelen, B. Ronchi, F. Vandevenne, G. Govers, R. Merckx, O. Batelaan, E. Struyf, J. Diels **(Theme 2)**

Transport of dissolved organic phosphorus (DOP) from soil to surface water on different land uses

09:00–09:30 Noura Ziadi, A.J. Messiga, C. Jouany, P. Virkajärvi, R. Suomela, S. Sinaj, G. Bélanger, C. Stroia, C. Morel **(Theme 3)**

Phosphorus budget as a tool to monitor soil P changes under grasslands

Tom Sims, P.N.C. Murphy, D. Wall. **(Theme 4)**

Managing legacy soil phosphorus to sustain agriculture and protect water

09:30–10:15 Martin Blackwell, R.A. Matthews, T. Darch, A.L. Collins **(Theme 5)**

Phosphate saturation in riparian buffer strips

Dennis Collentine, H. Johnsson, K. Persson, H. Markensten, P. Larsson **(Theme 6)**

The comparative cost efficiency of three buffer zone programs to reduce phosphorus losses in a small Swedish catchment

Petri Ekholm, J. Lehtoranta, S. Wahlström **(Theme 3)**

Simulating the release of soil phosphorus in sulphidic sediments

10:15–11:30 Coffee and Poster session

11:30–13:00 Concluding presentation and discussion

13:00 Lunch (take away)

SCIENTIFIC ADVISORY COMMITTEE

MARIANNE BECHMANN

Marianne Bechmann (Dr Sci.) has been working with diffuse pollution from agriculture for 25 years. Her main work is at the intersection between research and management, with focus on measures to improve water quality. She is responsible for erosion and nutrients in the long term (20 years) monitoring programme in Norway (JOVA) and edited a book on this topic in 2013. Erosion and runoff of nutrients is the main focus of most of her work including identification of nutrient sources in the agricultural landscape, processes for nutrient loss and quantification of effects of mitigation measures to reduce the losses from soil to water. She was responsible for the development of the Norwegian P index for identification of critical source areas and has further developed a management tool to estimate cost-effectiveness of mitigation measures. Her studies range from monitoring at the catchment scale to plot and lab. scale experiments with the main purpose to identify the most appropriate mitigation measures for both the environment and food production.

PETER KLEINMAN

Dr. Peter Kleinman is the Research Leader of the USDA Agricultural Research Service's Pasture Systems and Watershed Management Research Unit in State College, PA. A soil scientist by training, Dr. Kleinman explores the interactions between land management and landscape processes that control the transfer of nutrients from land to water. His specialty is in the study and management of phosphorus, an element he has pursued from the rainforests of Borneo to the pastoral landscapes of the Chesapeake Bay watershed. He obtained his PhD in Soil Science

from Cornell University in 1999. He is a Fellow of the American Society of Agronomy and a Fellow of the Soil Science Society of America.

OSCAR SCHOUMANS

Oscar Schoumans works as a Senior Scientist at Alterra Wageningen UR (University and Research Centre). He is working for more than 25 years on the emissions of nutrients to groundwater and surface water and the impact of nutrient management strategies on water quality. He is involved in numerous laboratory, field, regional and national studies. Since 1996 he supervised a number of Research Programs of the Ministry of Agriculture, Nature, and Food Quality. The main research themes of these Research Programs focus on the implementation of European Nitrate Directive and Water Framework Directive and in particular to monitoring aspects, effectiveness of mitigation options, national ex post evaluations of the Manure Act and long term scenario analysis. Over the last 7 years more attention is paid to increase the resource efficiency of phosphorus, on closing the nutrient cycle and on the nutrient recovery from "waste" streams into valuable products.

ANDREW SHARPLEY

In 2006, Andrew Sharpley joined the Department of Crop, Soil and Environmental Sciences, University of Arkansas, Fayetteville, where he is Distinguished Professor of Soil and Water Sciences and Director of the Arkansas Discovery Farm. He received degrees from the University of North Wales, United Kingdom in 1973 and Massey University, New Zealand in 1977, and spent 25 years with the USDA-ARS

in Oklahoma and then Pennsylvania. His research investigates the cycling of phosphorus in soil-plant-water systems in relation to soil productivity and water quality and includes the management of animal manures, fertilizers, and crop residues. He also evaluates the role of stream and river sediments in modifying phosphorus transport and response of receiving lakes and reservoirs. He developed decision making tools for agricultural field staff to identify sensitive areas of the landscape and to target management alternatives and remedial measures that have reduced the risk of nutrient loss from farms and works closely with producers, farmers, and action agencies, stressing the dissemination and application of his research findings. He is the Editor-in-Chief of the Soil Science Society of America, Fellow of the American Society of Agronomy and Soil Science Society of America and received their Applied Soil Science and Environmental Quality Research Awards. In 2008 was inducted into the USDA-ARS Hall of Fame, and in 2012 received the Christopher Columbus Foundation Agriscience Award. Dr. Sharpley serves on National Academy of Science and EPA Scientific Advisory Boards.

CHRISTIAN STAMM

Christian Stamm has a background in biology and holds a PhD in soil physics. He is deputy head of department of Environmental Chemistry at the Swiss Federal Institute of Aquatic Science and Technology (Eawag) and lecturer at the Swiss Federal Institute of Technology (ETHZ) in Zürich and member of the ETH World Food System Center (WFSC). Since more than 20 years he works on transport of agrochemicals with a main focus on phosphorus and pesticides. His research has a strong focus on experimental studies on catchments of first and second order streams and the modelling of the resulting spatial loss patterns. In recent years, he has ex-

panded the range of research topics by first including urban sources of diffuse pollution and second by linking the water quality aspects in interdisciplinary projects with questions on ecological effects in stream ecosystems under current and future climatic conditions.

RISTO UUSITALO

Risto Uusitalo holds a PhD degree in Soil and Environmental Sciences from the University of Helsinki since 2004. He has worked at MTT Agrifood Research Finland since 1997 on P delivery pathways, P availability assessment in agricultural and ecological contexts, on tillage effects on runoff quality, on the follow-up of the Finnish Agri-Environmental Programmes, as well as on soil classification. The most recent works has dealt with options to curb P losses from agricultural soils to surface waters by chemical amendments.

PAUL WITHERS

Paul Withers is Professor of Geography at Bangor University specialising in rural land management, environmental pollution and water quality. As a soil and catchment scientist, his main research focus over the last 20 years has been the cycling, transfers, impacts and management of phosphorus in terrestrial and aquatic ecosystems. His current research interests are developing sustainable systems of food production, diffuse pollution and eutrophication control and the coupling of C, N and P cycles across the land-water interface. He is technical lead for a project exploring the sustainable management of phosphorus in arable systems and leads the in-stream component of a project investigating the links between nutrient cycling and provision of ecosystem services.

INTRODUCTORY KEYNOTE PRESENTATION



Introductory Keynote Presentation:

FUTURE AGRICULTURE WITH MINIMIZED PHOSPHORUS LOSS TO SURFACE WATERS

Sharpley A.N.¹

¹Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville, AR, USA

sharpley@uark.edu

It is almost 20 years since the first International Phosphorus (P) Workgroup meeting in Wexford, Ireland in 1995, when the attendees focused on broadening our understanding and management of P loss from agriculture to water. In many ways, we have come a long way since then; however, we are still challenged to affect widespread and lasting reductions in P loss and P-related impairment of receiving waters and we still struggle to attain that fine balance between production and environmental sustainability. This Conference and paper will outline critical knowledge gaps, managing risk, transferring science to the farm, and adapting to the demands future climate change and population increases on P sustainability.

The accelerated eutrophication of freshwaters and to a lesser extent some coastal waters is primarily driven by P inputs, predicating its management in point and nonpoint sources. While efforts to identify and limit point source inputs of P to surface waters have been successful, nonpoint sources have remained elusive and more difficult to identify, target, and remediate. As further reduction in point sources discharge of P via innovative wastewater treatment technologies becomes increasingly costly, attention has focused more on nonpoint source reduction, particularly the role of agriculture. This attention was heightened over the last decade by a number of highly visible cases of nutrient-related water quality degradation; including the Baltic Sea, Chesapeake Bay, Florida's inland and coastal waters, Gulf of Mexico, and Lake Erie. Compounding concerns, is the fact that water quality has not improved as quickly or as widely as expected after adoption of conservation measures. This presentation will focus on two case studies, which highlight several "challenges" facing P management, affecting water quality improvements, and foreseeing direct and indirect consequences of management and climate shifts.

The recent increase in P impairment of Lake Erie provides an excellent example of many of these issues as well as working with risk-averse farmers. With changes in nutrient management and cultivation to minimize P loss in Lake Erie catchments, came a shift in dominant pathways of loss and new critical sources areas were created. Steady declines in P inputs from predominantly agricultural catchments were measured between 1980 and 1995 with increased nutrient management planning that reduced fertilizer and manure applications and a transition to no-till cropping. However, increased P inputs over the last decade resulted from a complex dynamic, but yet predictable accumulation of P at the soil surface, continued broadcasting of P, a focus on BMPs for particulate P loss, release and remobilization of fluvial P, and a rapid rise in tile drainage fuelled by increased by higher grain prices. The combination of these created a "perfect P loss storm," which along with more intense summer rains increased P inputs to Lake Erie to record levels in 2010 onwards. However, scientifically valid remedial strategies were not likely to be adopted by farmers due to several

logistical, practical, and cost limitations. Clearly, the research community needs to work closely with the farming community to generate innovative support, stewardship, reward, and trading program that will empower change.

The second case study is documenting reduced nutrient inputs to the Chesapeake Bay from nearly 30 years of programmatic implementation and modeling within the watershed. The Chesapeake Bay Watershed is globally unique in the fact that it has an order of magnitude greater ratio of land area to water volume than any other watershed ($2410 \text{ km}^2:\text{km}^3$ compared to $380 \text{ km}^2:\text{km}^3$ for the Gulf of Finland). Also, intensive agricultural production is located near the Bay and its major tributaries, while natural forest buffers are located in distant, headwater areas. Lesson we can learn from a perceived lack of success in remediating the Bay include unrealistic goal setting based on inadequate models, a lack of accountability and verification of implemented BMPs, and an underestimation of legacy effects of both land management attitudes as well as fluvial stores of P.

The literature shows the response to management change can range from months to centuries and differ along the soil (5 to 15 years), river (1 to 5 years), and lake (10 to 30 years) catchment continuum. To a large extent, economics remains the main driver and barrier to achieving P sustainability. More costly P fertilizers have encouraged soil testing, its more conservative use, increased the value of manure, and the recycling of other by-products as P-rich resources. As the increased cost of treating waste and P-impaired waters, BMPs (one “low hanging fruit” have been addressed), innovative options, such as struvite generation, dewatering manures, and separating liquid and solid waste streams, become increasingly cost effective. Finally, we have sophisticated models and risk assessment tools but a limitation to their accurate use remains a lack of reliable input data to run, calibrate, and validate them.

Theme 1

ORAL PRESENTATIONS

P management in a changing world
– effect of climate change, P deficiency and
increasing population



Keynote lecture:

PHOSPHORUS MANAGEMENT IN A CHANGING WORLD – COPING WITH THE EFFECTS OF AN INCREASING HUMAN POPULATION, RESOURCE SCARCITY AND CLIMATE CHANGE

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Our society has to deal with a number of important developments and issues, which affect nutrient cycles at different scales. Both, the increase of the human population, urbanization, changes in diets, and the further agglomeration of animal production, lead to an increasing demand of fertilizer nutrients, a further intensification of the agricultural production, an increasing transport of nutrients in food and feed, and an increasing need to recycle wastes properly. Also, the upcoming bio-based economy increasingly competes with the food production sector for scarce land, water and other natural resources. Moreover, effects of climate change, water resource depletion, soil degradation and air pollution increasingly set constraints to biomass production. We believe that these developments and issues negatively affect nutrient use efficiency, and water and air quality, unless a coherent package of nutrient management strategies and measures are implemented. Our ideas build upon the strategies recently proposed in the report “Our Nutrient World”. We plea for nutrient management strategies that consider the whole food production – processing – consumption chain, including food losses and household waste recycling.

Within the food production sector, nutrient use efficiency in crop and animal production will have to increase to be able to decrease nutrient losses to air and water bodies. Of great importance is also the need to recycle organic matter and nutrients from food losses and household wastes in crop and animal production systems. Decisions will have to be made about the allocation of organic matter to food, feed, fuel and soil; it has to be accepted that soils require input of soil organic matter for long-term sustainability. Of key importance are also measures to reduce phosphorous (P) losses to water bodies, and to re-use and recycling P in residues, wastes and bio-solids back to agricultural land effectively. This holds especially for Europe, as it has no significant P rock reserves. Because of its dependency on imports via fertilizers, food and feed, and the relative scarcity of global P reserves, prices of P containing products tend to become more volatile.

Phosphorus balances of European countries show relatively high P inputs via import of P fertilizers and animal feed. The crop and animal production sectors consume more than 80% of all imported P in Europe, and the industry less than 20%. About 55% of the P inputs in the crop and animal production sectors in Europe is harvested again in crop and animal produce, while the remaining 45% is largely accumulating in agricultural soils or lost via leaching to water bodies. The P

in crop and animal produce is largely consumed by households (or exported to other countries), and ultimately ends up in waste streams. These waste streams are recycled back to agricultural land in some countries in Europe, but mostly end up in landfills, sediments and/or road infrastructure (following incineration). There are several technical options and innovations to re-use the P from waste streams, but these have not yet been implemented fully.

The amount of P in animal feed is often higher than the requirements of the animals, because the P content and the market prices of the feed ingredients determine to some extent the composition of the feed. Moreover, not all P in feed is available to mono-gastric animals, which lead to relatively high uncertainty ranges in P contents of compound feeds. Recent studies suggest that changes in the combination of feed ingredients can lead to a lowering of the P content with just a small increase of the prices (< 4%) of the compound feeds. Furthermore, bio refinery may help to increase the digestibility of the P in feed ingredients and may also extract excess P. Studies suggest that the P content of the animal feed may decrease further by some 20-25% if the potentials of bio-refinery are utilized fully.

Manure processing and transport of processed manure fractions is likely an option for animal farms that have insufficient land nearby to dispose of the produced animal manure in a way that can lead to a high nutrient use efficiency. Separation of the animal manure in a liquid fraction that is relatively rich in nitrogen and potassium, and in an organic matter and P rich solid fraction may facilitate the optimization of the N and P use efficiency. However, manure processing is not without (energy) cost.

Additionally there are options to retrieve N and P from animal manure and household waste and produce secondary resources for N and P consuming industries. However, in some cases EU or national legislations have to be adapted to allow those new sources of nutrients as fertilizer. One of the options is reverse osmosis of the liquid manure fraction, to produce a nitrogen rich mineral concentrate and a clean permeate which can be discharged to the surface water. The nitrogen fertilizer replacement value of mineral concentrate is comparable with conventional calcium ammonium nitrate fertilizers. However, the EU Nitrates Directive states that all products derived from animal manure are animal manure, and have to comply with the manure rules of the Nitrate Directive. There is also much attention on the production of struvite (magnesium ammonium phosphate) from communal waste streams, process water of food and feed industry and manure treatment. However, in some countries it is only allowed to apply struvite from human or animal resources on agricultural land after sanitation treatment. Since, most of the P in food system biomass streams is accumulated in the solid fraction of manure, there are many initiatives to concentrate the P content even further, e.g. by incineration into P ash or pyrolysis into a P-biochar. The cost of incineration is relative high and valuable components such as organic matter and N components are lost. The production of organic rich P-biochar is also costly and the added value as soil amendment fertilizer is questionable. Recently, there is more focus on simpler and cheaper techniques to recover P from animal manure in order to increase the application of treated manure on agricultural (arable) land and reduce the transport of P surpluses from intensive livestock areas.

In addition, climate change, water resource depletion, soil degradation and air pollution increasingly set constraints to biomass production. Modelling results show that annual mean temperature in Europe is likely to increase from 1 to 5.5°C depending on the scenario. Southern Europe likely will be more affected, with higher temperature and extreme summer droughts. Northern

Europe will experience less temperature increases (1-4°C), with mainly winters getting less cold and less frozen days. Temperature extremes will decrease in the winter, but increase in the summer. Annual average precipitation will increase in northern and north-central Europe, while it will decrease in southern Europe. Annual precipitation patterns will also change. Southern Europe will experience lower rainfalls all year round. There will be less precipitation during summer time in Atlantic and continental Europe, but more winter precipitation. Furthermore, more extreme precipitation events are expected all over Europe. Northern Europe will face lower summer rainfall and more storms. The Baltic regions will see higher coastal erosion due to more frequent and stronger winter storms. The average temperature increase in these regions will be relatively modest. Atlantic Europe will face increasing winter rainfall, dryer summers and more winter floods. Continental Europe will face higher winter rainfall, more winter floods, and lower summer rainfalls with subsequent higher risks of summer droughts. Temperature increases will be significant. Mediterranean Europe will face more extreme temperature increases, continuous droughts and occasional flash floods.

It is obvious that those events will have an impact on agricultural production (crop growth), nutrient cycling in soil-water-systems, losses to the environment, water quality and ecological systems. The increase of temperature will increase the decomposition of organic matter and a release of more inorganic nutrients, but the overall effect on the nutrient concentrations in the soil-groundwater system will depend on the cropping system, adjusted fertilizer strategies and other turnover processes. However, the nutrient losses to surface water are highly determined by the net seasonal precipitation surplus and the frequency of high precipitation events/intensities. It is expected that the more peak events will increase nutrient losses to surface water by erosion/ surface runoff and subsurface runoff. Studies also suggest that the load of phosphorus will remain stable under various climate change scenarios. However, due to lower flow discharge an increase of phosphorus concentration in surface water could be expected. Measures to reduce the nutrient losses have been inventoried, published and are more communicated to the farmers. However, the effectiveness of many of those measures is not well known. Some are cheap and in fact no-regret action. On the other hand, some seems to be very effective but are expensive. In order to protect also our fresh water systems in the future more evidence is needed under which circumstances nutrient losses can be cost-effectively reduced.

During the presentation the consequences of the increase of population and climate change will be shortly presented based on the results of scenario studies. The major focus will be on strategies and options to deal with this global climate change in relation to increasing nutrient efficiency, recovery and re-use of nutrients from waste streams, and measures to reduce the losses to groundwater and surface water. This will be the start up for a further debate within (and hopefully also outside) our international phosphorus network.

CLIMATE PROOFING PHOSPHORUS MANAGEMENT: A MODEL BASED ASSESSMENT OF TRADEOFFS AND UNCERTAINTIES

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Changing climate, land use and population can all have deleterious effects on water quality. Models are often used to understand the range of possible interactions of these drivers, assess potential efficacy of management actions and identify potential barriers to pollution control. INCA-P, the Integrated Catchments Model for Phosphorus, has been used to simulate phosphorus (P) dynamics in rivers in Canada and the UK so as to better understand causes of present day eutrophication and evaluate possible climate change effects on nutrient control strategies.

The INCA-P model simulates effects of sewage treatment works (STWs), diffuse agricultural inputs and in-stream retention on surface water P concentrations. The model can be used to explore climate change scenarios and to assess the efficacy of P control measures including restrictions on point source discharge, fertilizer management and erosion control measures on in-stream P concentrations.

INCA-P was applied to the River Thames, the main water supply for London. The river is eutrophic with significant algal blooms. P is available from STWs, agriculture and diffuse urban sources. Scenarios of future climate and land use change suggest worsening water quality but mitigation measures may improve the situation. The most effective strategy is a 20% reduction in fertiliser and enhanced treatment of STW effluent, potentially bringing in-stream P concentrations close to the WFD target for the Thames.

In Canada, INCA-P was applied to the Black River, a tributary of Lake Simcoe, a regionally important water body at risk of eutrophication from excessive P loading. The effectiveness of P management strategies in a changing climate were assessed by simulating controls on STW discharge, limiting fertiliser applications, and controlling sediment inputs. Increased winter precipitation and less snow cover will lead to higher diffuse P inputs. Management scenarios could not fully compensate for these climate change impacts on Black River P loads.

Model results from both Canada and the UK suggest that climate change will exacerbate problems with elevated surface water P concentrations and reduce the effectiveness of control measures. They also show that combinations of management measures targeting both point and diffuse sources are more likely to be robust to a changing climate and show the greatest promise of success.

ARE DUAL GOALS OF INCREASING P AVAILABILITY TO CROPS AND INCREASING SOIL C MUTUALLY EXCLUSIVE?

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Two principal objectives of sustainable agriculture are to (i) increase availability of key nutrients to crops and minimise system inputs of non-renewable resources such as P and (ii) maintain soil structure, function and mitigate against climate change by increasing soil C contents. We focus on forms of P and C in temperate soils and whether increasing soil C will shift soil P towards complexed forms that decrease P availability to crops.

Variation in combinations of soil organic carbon (SOC, 12-449 g C kg⁻¹) and P inputs (total P contents 104-2965 mg P kg⁻¹) were maximized in sampling thirty-two UK temperate topsoils, which were analysed for P species by ³¹P-NMR spectroscopy on NaOH-EDTA extracts, biogeochemical properties and standard P indices. The forms of P in the NaOH-EDTA soil extracts showed variation across land use classes linked to P stabilisation controls such as amounts of SOC and amorphous Fe and Al and microbial indicators of water extractable organic carbon (WEOC) and microbial P. Soils within different land use groups separated out along a positive relationship of organic P/inorganic P ratio vs C:P balance ($p < 0.001$), where mineralization in arable soils and immobilization in grassland and semi-natural land use soils limits and increases organic P storage respectively. The relationship was strongest using WEC to account for the lability of the SOC.

We further explored such relationships using global soil data from other studies. We question the strength of the link between C and P cycling and whether key soil services of P supply and C storage really do compete, or whether such relationships are a product of fertiliser inputs or site land use constraints. We explore the implications of any mechanistic links in P and C cycling, including optimising crop acquisition of complexed P forms, or considering that different soils may need to be favoured for cropping and C sequestration targets.

WHY DO WE STILL SPRINKLE SALTS ON THE SOIL: PHOSPHORUS?

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Current strategies of phosphorus (P) fertiliser use are based on feeding the soil to feed the plant. There are large inefficiencies associated with this strategy due to the immobilisation of fertiliser P by soil, the limited volume of the soil that roots can explore, the large number of environmental factors that can limit the diffusion of P from the soil to the root and the uncertainties associated with soil sampling, analysis and interpretation. For example, current estimates suggest that between 5 and 10 million tonnes of P are held in UK soils in forms not extracted by Olsen's reagent, and by inference not crop available. These inefficiencies are not sustainable if the finite reserves of rock phosphate are to be preserved for as long as possible and if environmental damage (eutrophication) associated with soil P accumulation is to be reduced. We present new data suggesting that runoff dissolved P concentrations in runoff from soils maintained at current agronomically optimum Olsen-P concentrations are still too high for effective eutrophication control in rivers. Fertiliser is also the biggest variable cost in crop production so it is worth investing in ways to use less.

We therefore argue for a new strategy that relies far less on the soil and more on innovative technologies to improve P use efficiency; i.e. farming on soils with lower Olsen-P. Three innovative strategies are proposed to improve sustainable P use: (i) minimise crop P requirements, (ii) maximise root recovery of total soil P, and (iii) target fertiliser more precisely to meet critical growth phases (e.g. early crop establishment) and with as complete P recovery as possible. Plant metabolic need for P may only be 40% of total P uptake with the remainder stored in forms (phytate) which are not nutritionally useful. Soil P acquisition remains difficult to predict as critical Olsen-P concentrations for growth can vary 3-4 fold between sites and seasons. Recycled and recovered P could more effectively substitute for inorganic fertiliser and improve soil quality in the longer term, but their use is currently constrained by economics, spatial disconnects and variability in quality. The challenges this new approach present are explored within the context of sustainable intensification, protection of natural capital and the environment and the provision of ecosystem services.

PLANT UPTAKE OF PHOSPHORUS RECYCLED FROM HUMAN URINE AND SEWAGE SLUDGE ASHES

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The growing human population and urbanization result in greater phosphorus (P) fluxes from the agro-ecosystems to consumers and into the waste water. Various technologies to recover the finite P resource from these waste streams are available. Urine contains about 50% of P excreted by humans. If collected separately, struvite ($\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$) can be precipitated. A new technology first nitrifies urine biologically and then distills it to produce a concentrated liquid fertilizer. Another option is the recycling of P from sewage sludge incineration ashes by removing the undesired heavy metals or by selective P recovery. In either way the recycling of P back to crop land requires that the availability of the P to plants is known.

We studied the P uptake by plants from synthetic nitrified human urine solid (SNUS), struvite (STRUV) precipitated from synthetic human urine and P recovered from sewage sludge ashes (SSA) by either a thermo-chemical (SSA-tc) or a chemical process (SSA-c). We used radioisotope labeling to determine the P in ryegrass taken up from the fertilizer. Experiments were performed growing ryegrass over several regrowth cycles under controlled conditions in the greenhouse.

The results show that P contained in the urine-based fertilizers is readily available to plants growing on a slightly acidic soil. Twenty-six % of P applied with SNUS or STRUV was recovered by ryegrass, which was similar to the 28% of P recovered from water soluble mineral P. Likewise, P uptake from SSA-c and SSA-tc was similar to P uptake from water soluble mineral P on this same soil. On neutral and alkaline soils, P contained in SSA-tc was significantly less available than water soluble P, while SSA-c remained a readily available P source. Overall, our results suggest that P recycled from human urine and sewage sludge ashes has the potential to become valuable P fertilizers. These findings could trigger the implementation of systems combining sanitation facilities with P and further nutrients recovery.

Theme 2

ORAL PRESENTATIONS

Transport pathways of P from soil to water
– partitioning and dominance of different flow paths



Keynote lecture:

TRANSPORT PATHWAYS OF P FROM SOIL TO WATER – PARTITIONING AND DOMINANCE OF DIFFERENT FLOW PATHS

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Water flow is generally the driver for phosphorus transfer from soil to water bodies. This presentation will first elucidate how the interplay between soil chemistry and hydrology controls the flow paths that are relevant for P losses from agricultural land to (surface) water bodies. The starting point is the traditional view that P sorbs strongly to most soils. The presentation explores under which conditions reality deviates from this view and how this affects transport patterns of P and the relevant transport processes involved. Subsequently, these flow paths will be examined in some more detail. The view that one can clearly distinguish between well-defined transport processes like surface runoff versus subsurface flow is challenged by demonstrating how complex process chains may occur in the landscape. It will be also shown how artificial structures influence these transport pathways. While these insights render the picture of P transfer within catchments more complex it can be also shown that new remote sensing data like high resolution digital elevation models may be used to for advances spatial analyses that are useful for practical applications.

Finally, the presentation will put the discussion of how important different flow paths are in the context of the ecological endpoints that are considered. Depending on whether one is interested in conditions in streams or in lakes and estuaries, different flow paths and processes may be of importance.

PHOSPHORUS FORMS AND CONCENTRATIONS IN SNOW MELT RUNOFF FROM SASKATCHEWAN CROPLAND AND PASTURE

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Runoff can be a key contributor to the loss of phosphorus (P) from agricultural lands to water bodies. Beneficial management practices (BMPs) have been developed to minimize P loss. However, to maximize the benefit of BMPs it is important to understand the physical and chemical forms and concentrations of P in runoff, because physical and chemical P forms differ in their transfer mechanisms and their reactivity in the environment. The Canadian prairie region is unique in that its hydrology is characterized by long periods of winter, with half the annual precipitation occurring as snowfall. During spring snowmelt, there is a rapid release of water from snow packs when the mineral soil is frozen, resulting in high surface runoff. In 2009, a project was initiated in SE Saskatchewan to study BMPs for the key agricultural practices in this region (annual crop and beef production). This study confirmed that snowmelt is the predominant source of runoff from land in this area; only extreme rainfall events at other times of the year generated runoff, with nutrients in snowmelt moving predominantly in dissolved forms while those in summer storms move in particulate form. To better understand P loss in runoff, we used ³¹P-NMR spectroscopy and chemical analysis to characterize the P forms and concentrations in dissolved and particulate edge-of-field snowmelt runoff samples collected in 2011. Over the six-day runoff event, our results showed no significant differences in total dissolved P concentration from cropland versus pasture, but higher total particulate P concentrations from pasture relative to cropland. Dissolved P from both cropland and pasture was predominantly orthophosphate, with only traces of organic P forms. In contrast, particulate P from both agricultural systems was dominated by organic P forms, especially orthophosphate diesters. ³¹P-NMR spectroscopy was sensitive enough to show temporal differences in P forms within a single runoff event, allowed the determination of flow-weighted concentrations of P forms, and allowed the identification of specific P forms, including agricultural chemicals such as glyphosate in snowmelt runoff from annual cropland. These results will further our ability to develop appropriate BMPs to manage P loss from agricultural soils in this region.

MULTI-ELEMENT HYDROCHEMICAL SIGNATURES TO EXPLORE PATHWAYS AND ATTENUATION OF PHOSPHORUS IN KARST TERRAIN

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Across the world, rivers draining karst terrain are potentially vulnerable to phosphorus (P) and nitrogen (N) loss to receiving waters, in both dissolved and particulate forms, via solution-widened conduit pathways. This study uses multi-element hydrochemical signatures (including a wide suite of major and trace elements), to examine how different water flow pathways influence P and N transport and delivery in a karst landscape. Our study area, the Illinois River Watershed in northwest Arkansas, drains the Ozark Highlands, a major area of beef and poultry production, which is characterised by karst limestone topography and shallow cherty soils. In the Illinois River, baseflow groundwater inputs from the karst account for c. 67% of annual river flow, rising to c. 80% in summer. Rapid flow pathways in the karst are also responsible for transmission of runoff during storm events, in combination with direct surface runoff pathways.

This study evaluates how water pathways, from surface runoff and rapid conduit flow, to slower, delayed flow through the epikarst, influence P concentrations and fluxes from a series of springs at the University of Arkansas' Savoy Experimental Watershed, which drains into the Illinois River. Spring water chemistry was compared with the endmember chemistry of surface runoff from field plots, established in pasture land above the springs. The field runoff plots were subject to rotation livestock grazing. Endmember-mixing analysis allows us to examine the non-conservative behaviour of analytes, relative to conservative markers, during mixing of different water sources under changing flow conditions. We used multi-element signatures of runoff from pasture plots and groundwater water sources to explore the pathways and dynamics of P delivery to the springs, and to evaluate the retention and subsequent flushing of a 'legacy' of nutrients stored along subsurface flow pathways. Pathways of water movement through the karst exert a major control on river water quality across the upper Illinois River Watershed, and the results of this study are discussed in relation to meeting downstream water quality criteria (0.037 mg-P L⁻¹). This numeric concentration criterion was promulgated by Oklahoma for the Illinois River as it flows from Arkansas across the state line into Oklahoma, and is the subject of continuing debate and assessment.

CATCHMENT INTEGRATED PHOSPHORUS TRANSFER PATHWAYS WITHIN THE AGRICULTURAL LANDSCAPE

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Using high-resolution and synchronous phosphorus (P) concentration and discharge data, we demonstrate a method to identify and quantify P transfer pathways in agricultural landscapes. Combining the data into instantaneous time-series P loads, segments between inflexion points in storm recession limbs were separated logarithmically. In this *Loadograph Recession Analysis* each segment was assumed to represent the release of P load *via* different flow pathways; separated into *quick flow (QF)*, *interflow (IF)* and *delayed flow (DF)*. The interpreted *QF* was supported by elevated turbidity and the *DF* by a comparison to stream and groundwater quality and to chemical mixing diagrams. Interpreted pathways were coupled to a geological model derived from geophysical measurements. The method was applied to a summer (Jun) and winter (Jan) storm event in two *ca.* 10 km² Irish agricultural catchments with predominantly permeable soils. One catchment was dominated by *arable* land overlying slate bedrock and the other by intensively managed *grassland* on sandstone. In the *Arable* catchment there was no seasonal difference in the relative proportion of total reactive P (TRP) pathways (*QF* = 35%, *IF* = 4% and *DF* = 61% of event total). For total P (TP) transfers there were, however, seasonal differences with proportionally more *QF* in the summer event (73%) than in the winter (53%) and the *DF* transfer was consequently lower in summer (25%) than in winter (44%). The highest flux was in the winter *QF* for both TRP and TP (0.13 g TRP ha⁻¹ h⁻¹ and 0.52 g TP ha⁻¹ h⁻¹). In the *Grassland* catchment there were seasonal differences for both TRP and TP. For TRP transfer the *QF* was proportionally higher in summer (48%) than in winter (33%) and the *DF* was lower in summer (47%) than in winter (62%). Also the TP transfer was proportionally higher in summer *QF* (55%) than in the winter *QF* (48%) and the *DF* was lower in summer (39%) than in winter (48%). Also in this catchment the highest flux was in the winter *QF* for both TRP and TP (0.38 g TRP ha⁻¹ h⁻¹ and 1.07 g TP ha⁻¹ h⁻¹). Both catchments had a large proportion of P transfer in the below-ground delayed flow due to the relatively high concentrations of P in the nearstream groundwater and due to the streams being mostly groundwater fed. This analysis suggests that policies such as surface placed buffer strips may only be partly effective in some catchments.

TRANSPORT OF DISSOLVED ORGANIC PHOSPHORUS (DOP) FROM SOIL TO SURFACE WATER ON DIFFERENT LAND USES

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While it is well known that agricultural activities may lead to significant increases of P loading of surface waters, the pathways through which P and in particular dissolved organic phosphorus (DOP) is transferred from the land to the river are less well understood. It was recently found that DOP is mostly bio-available to algae and hence high DOP concentrations may impair surface water quality. We studied three headwater catchments (30 – 300 ha), all located in Belgium but having different land uses (forest, arable land, grassland). We monitored different fractions of dissolved ($<0.45 \mu\text{m}$) phosphorus (P) in the river and in soil- and groundwater from January 2011 onwards in order to gain a better understanding of how land use changes may affect both DOP fluxes and pathways.

In general, the fraction of DOP concentration in the stream samples was low to negligible, but during peak flows after a dry period, the concentration of DOP rose to a significant level. In the agricultural catchment (arable land) DOP accounted for up to 10% of the total dissolved P load in the stream during runoff peaks. This is important as discharge peaks can transport a great amount of P (15 g P ha^{-1}) in a short period of time from the soil to the surface water.

In the forested catchment there was a clear difference in total P concentration between summer and winter. In winter the concentrations were low ($<0.2 \text{ mg L}^{-1}$), even during runoff peaks. In summer, concentrations of total P could rise up to 0.6 mg L^{-1} in the baseflow. The rise in P concentration in the baseflow in summer can only be attributed to in-river processes, because no hydrologic pathway of P reaching the river can explain this particular rise in concentration. A hypothesis is that the breakdown of leaf litter or temperature driven microbial activity can be accounted for this rise.

In the grassland catchment the concentration of P was always low. During runoff peaks DOP concentrations rose slightly in comparison to the baseflow values. The concentrations of orthophosphate, colloidal P and DOP were found to rise together. This means that the water that was following a faster pathway was enriched in DOP and other P fractions in comparison to the baseflow. On a yearly basis, a total dissolved P loss of 1.3, 70.5 and $223.9 \text{ g P ha}^{-1}$ is lost from the forested, grassland and agricultural catchment respectively.

Theme 3

ORAL PRESENTATIONS

Monitoring, modeling and risk assessment at different scales – targeting critical source areas



Keynote lecture:

MONITORING, MODELLING AND RISK ASSESSMENT AT DIFFERENT SCALES – TARGETING CRITICAL SOURCE AREAS

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Phosphorus (P) is a main cause of eutrophication many lakes and rivers. In the agricultural landscape, various sources contribute P to the water bodies. It has been shown that the largest contributions of P often come from a rather small part of the agricultural area. Areas with vegetable and potato production or farms with intensive livestock production are some of the critical source areas in the agricultural landscape. This presentation will discuss the importance of monitoring and modelling for targeting mitigation measures for reduced P loss to the critical sources and sources areas.

Monitoring is required to identify sources and source areas of P. However, because of the dynamic nature of P loss, monitoring needs to cover also the high flow events. Continuous monitoring is carried out in the Norwegian Agricultural Environmental Monitoring programme. Data from this programme has shown the importance of soil erosion for total P loss from the agricultural landscape (Figure 1). The highest P loss occurs during erosion events and plot studies have also shown the best effect of mitigation methods during these events. For managers, however, continuous monitoring is often too costly and sampling often occurs at low flow. Consequently, changes in P loss due to implementation of mitigation measures may not be detected.

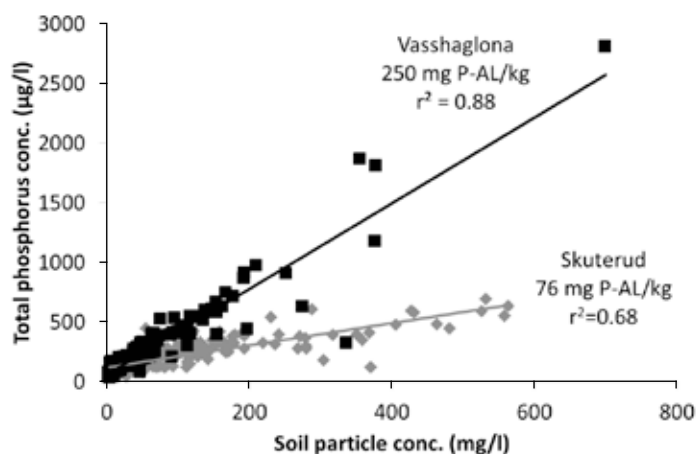


Figure 1. Concentrations of total phosphorus in relation to suspended sediments for two streams draining agricultural dominated areas with different soil phosphorus status (Bechmann and Deelstra, 2013).

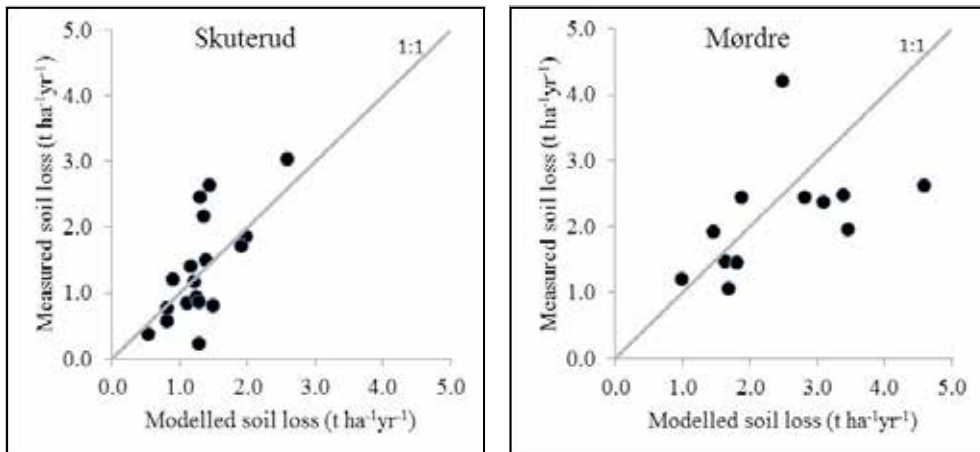


Figure 2. Relationship between modelled (Agricat) and measure soil losses from two Norwegian catchments dominated by agricultural production (adapted from Bechmann and Deelstra, 2013).

Tools and models may help the decision making by managers, who want to plan the most cost-efficient mitigation measures to reduce P losses. The P index tool is a simple tool to focus attention on the most important sources and processes of P loss. The Norwegian P index includes of erosion risk, factor for tillage effects and soil P status for identification of critical source areas. For management at the catchment scale, a similar approach, the Agricat model has been developed in Norway, summarizing P loss from single fields. Effect of soil tillage practices within two monitored catchments was calculated using Agricat and compared to the measured soil losses for each year (Figure 2).

The Agricat-model is a simple tool with a substantial uncertainty. However, most studied on modelling P loss seems to have a large uncertainty even with advanced physically based models. A challenge for scientists is to develop simple, precise and cost-effective methods for monitoring and modelling P losses at the catchment scale.

Bechmann, M. and Deelstra, J. 2013. (Eds.), *Agriculture and Environment – Long Term Monitoring in Norway*. Akademika Publishing, Trondheim. ISBN 978-82-321-909014-9.

INTEGRATING SCALES – DISTRIBUTED, HIGH-RESOLUTION MODELING OF EROSION AND PHOSPHORUS LOSSES

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Linking sources and mobilization of nutrients with their impact on water recipients requires identification and quantification of the delivery part of the P transfer continuum. Similarly, the mitigation options aimed at improving the status of an at-risk water recipient must take into consideration the spatial and temporal variability of diffuse sources. Paradoxically, this is because the diffuse losses are not as diffuse as was once thought. Today, high-resolution LiDAR (Light Detection and Ranging) elevation data (2-m grid) is available for large parts of Sweden which makes it possible to develop high-resolution distributed models capable of taking into account small scale variability and at the same time effectively integrate small computational units (grid cells) into larger entities, such as fields and catchments. Here, the (distributed) USPED (Unit Stream Power Erosion Deposition) model has been further developed to enable dynamic modeling within the framework of the PCRaster collection of software targeted at the development and deployment of spatio-temporal environmental models. The model performance regarding spatial variations was compared to field surveys of erosion and surface runoff occurrences, whereas models ability to capture temporal variations was evaluated by comparisons with measured time series of water quality. The achieved results show that distributed high-resolution model was able to account for high spatial variation in erosion and surface runoff patterns, and to integrate different management and hydrological scales (parcel, field, farm, landscape, catchment). Rill and gully erosion and surface runoff pathways documented by field survey were successfully and with high-precision identified by the USPED model. Also the temporal variation in monthly losses of suspended material was modeled at acceptable level, reaching Nash- Sutcliffe model efficiency values of 0.39. This means that high-resolution risk maps can be produced for large areas and provide decision support for cost-effective abatement efforts where an adaptive, field specific abatement strategy would cost less, free more land for agricultural production and increase reduction efficiency by targeting most vulnerable zones.

COMBINING MODELLING AND DIRECT MEASUREMENT TO QUANTIFY NUTRIENT SURFACE RUNOFF FROM FLAT FIELDS

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Surface runoff (SR) is a fast, and hence important, transport route for contaminants in rural areas, especially pesticides and phosphorus associated with sediments. There are two types: Hortonian SR (HSR, infiltration rate excess) and Dunne SR (DSR, storage capacity excess). HSR is less relevant in flat lowlands of temperate climate zones, because the ratio between the slope and heavy rainfall drivers and soil permeability is relatively low. If such lowlands are well drained, DSR is restricted to wet winter periods when shallow or perched watertables do not permit sufficient storage and percolation. Agricultural areas of the Netherlands that are subject to surface runoff comprise peat grasslands with ditches 30-60 m apart and water level <60 cm below the surface, heavy riverine clay grasslands with shallow trenches (<0 cm deep and 10-40 m apart), and mineral soils compacted by treading, tillage and heavy wheel loads.

Despite the low frequency of P loss events, SR is still significantly involved in P transport to lowland streams because of the severe incidental impact of the high nutrient concentrations in SR on surface water quality, and the substantial contribution to annual loads in the order of 1-15 kg N and 0.3-2 kg P ha⁻¹. The large variation in reported annual SR loads, even under similar circumstances, can be explained by its spatially and temporally variable nature, in combination with the shortcomings of the available measuring techniques. SR can only be measured directly where it is known to occur at preselected shorter lengths of water courses, thus leading to overestimated SR values for fields or catchments. Its incidental nature means that an observation period is seldom representative.

In an attempt to overcome these shortcomings, we combined 4-year direct SR measurements on three sandy soils with 3D dynamic SR modelling to analyse saturation, ponding and redistribution over the heterogeneous surface, including spill to the ditch. We measured the key surface features (micro- and meso-relief) that control SR response, assessed the representativeness of the measurement sites for the whole field, and estimated nutrient SR loads for the three fields.

INCORPORATING UNCERTAINTY ANALYSIS IN A FIELD-SCALE P LOSS MODEL

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Models are often used to predict phosphorus (P) loss from agricultural fields. While it is commonly recognized that model predictions are inherently uncertain, few studies have addressed prediction uncertainties using P loss models. In this study we assessed the effect of model input error on predictions of annual P loss by the Annual P Loss Estimator (APLE) model. Specifically, our objectives were to: (1) determine whether the relatively easy to implement first-order approximation (FOA) method provides accurate estimates of model prediction uncertainties by comparing results with the more accurate Monte Carlo simulation (MCS) method; and (2) to evaluate the performance of the APLE model against measured P loss data when uncertainties in both model predictions and measured data are included. Results showed that for low to moderate uncertainties in APLE input variables, the FOA method yields reasonable estimates of model prediction uncertainties (Figure 1), though for cases where manure solid content is between 14 – 17%, the FOA method may not be as accurate as the MCS method due to a discontinuity in the manure P loss component of APLE at a manure solid content of 15%. The estimated uncertainties in APLE predictions based on assumed errors in the input variables ranged from ± 2 to 64% of the predicted value. Of the 255 measured data points, confidence intervals for the model predictions and measured P loss data overlapped for 151 of them (Figure 2). Results from this study reveal certain limitations with the APLE model and highlight the importance of including reasonable estimates of model uncertainty when using models to predict P loss.

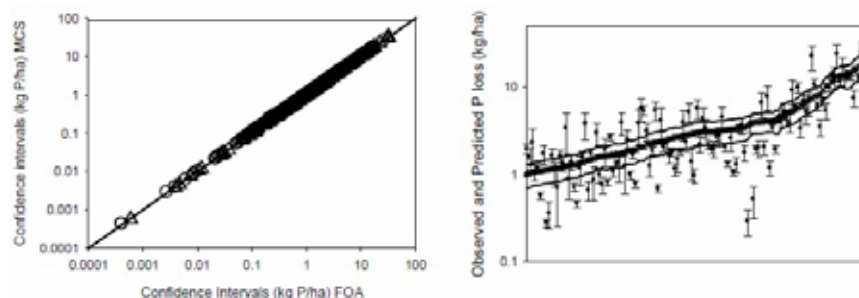


Figure 1. Comparison of confidence intervals calculated using FOA and MCS methods. Also included is 1:1 line. Confidence intervals calculated for manure solid content of 15% are not included.

Figure 2. Predicted (•) and observed (x) P loss along with 95% confidence intervals. Data shown are for studies with measured P loss of 1 kg/ha or greater (n=120).

PHOSPHORUS BUDGET AS A TOOL TO MONITOR SOIL P CHANGES UNDER GRASSLANDS

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Monitoring and managing soil P changes under different agro-ecosystems to improve P use efficiency and sustain agricultural production while protecting terrestrial surface water bodies remains a major issue for agronomists. Annual soil P budget, i.e. the difference between P inputs and outputs, can be used as a tool to assess P management using relationships between soil test P (STP) and cumulative P budget (Bcum). However, few studies have been conducted to evaluate this approach under grasslands production systems. The main objective of our study was to analyze the relationships between STP and Bcum in several long-term grasslands field experiments fertilized with varying P application dose. Six long-term grassland sites with two to four P fertilization rates (0 to 45 kg P ha⁻¹) were selected in four countries [France (Ercé and Gramond), Finland (Maaninka and Siikajoki), Switzerland (Petite Ronde), and Canada (Lévis)]. The STP was assessed according to existing guidelines: in France [Olsen P (P_{OI})], Finland [acidic ammonium acetate P (P_{AAH})], Switzerland [P_{AAE} (mixture of ammonium acetate, acetic acid and EDTA)], and eastern Canada [Mehlich-3 P (P_{M3})]. Annual soil P budgets were calculated as P applied minus P offtake, and Bcum was the sum of annual P budgets. At all sites and for all years, the Bcum was significantly different between P applications ($P < 0.001$). The Bcum varied from a minimum of -286.6 kg P ha⁻¹ at Gramond after six years of cropping to a maximum of 208.7 kg P ha⁻¹ at Lévis after 8 years of cropping. The STP significantly increased with positive and increasing Bcum except at Ercé while it significantly decreased with negative and decreasing Bcum occurred at all sites except at Ercé and Gramond. These results could be partly explained by the lack of the decrease of P_{OI} in French sites. Significant linear regressions ($r^2 > 0.64$) between STP and Bcum were obtained at all sites even though significant year-to-year variability was observed at Siikajoki and Lévis. We conclude that the P budget approach could be used as a tool to monitor long-term changes in soil P under grasslands production.

SIMULATING THE RELEASE OF SOIL PHOSPHORUS IN SULPHIDIC SEDIMENTS

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The bioavailability of river-borne P originating from the agricultural fields to algae in estuaries and coastal areas is unclear. While some of the P in eroded soil particles can be released in water phase (e.g. by desorption), most of the P ends up in sediments where anoxic processes dissolve P from particulates. The bioavailability of P has been determined with algal and desorption tests, and the redox-sensitive proportion has been estimated with chemical extractions simulating reducing conditions. We consider that sediments are in a dynamic state where redox-conditions are driven by the microbes, organic C and the electron acceptors in sediments. We carried out an experiment to simulate the anoxic conditions that agricultural soil meets in marine sediment. In the experiment we controlled the labile organic matter and the main electron acceptors, i.e. Fe(III) oxides and SO₄. We studied the anoxic release of P by incubating agricultural sandy clay soil having a moderate P status (69 mg kg⁻¹ Olsen-P) in a P-free brackish water nutrient medium at 10 °C in the dark for 308 days. We inoculated 10 µl of brackish sediment and added different amounts of acetate. The SO₄ concentration was fixed to 2.4 g l⁻¹. The experiment applied a quadratic response surface setup, the response variable being e.g. Fe²⁺ and dissolved P. The soil suspension turned black and H₂S was detected, indicating SO₄ reduction. The release of P from soil increased with the C added, up to 450 mg kg⁻¹, being twice that extracted with buffered dithionite, supposed to mimic chemical reduction of Fe by H₂S. About one third of P in the soil studied was released, when Fe oxides were microbially and chemically reduced by sulphides formed in microbial SO₄ reduction. The results suggest the high potential of eroded soil as a P source in sulphidic systems, such as the Baltic Sea or SO₄ polluted lakes. It seems possible to enhance the dissolution of P from field soil by adding labile organic C and simulate a highly reducing marine sedimentary environment. This approach may serve as an alternative method for estimating the potentially mobile P.

Theme 4

ORAL PRESENTATIONS

The importance of manure and cropping systems for P management – how do we reach long-term sustainability?



Keynote lecture:

THE IMPORTANCE OF MANURE AND CROPPING SYSTEMS FOR PHOSPHORUS MANAGEMENT – HOW DO WE REACH LONG-TERM SUSTAINABILITY?

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Specialized cropping systems, their geographical separation from livestock systems and the widespread use of relatively cheap, manufactured, highly water-soluble phosphorus (P) fertilisers in western agriculture have generated large nutrient imbalances and surpluses that are harming water quality, threatening biodiversity and human health and depleting finite reserves of rock phosphate. At the other end of the spectrum, a large proportion of world soils are deficient in P and farmers in many developing countries do not have the resources to build up soil P fertility leading to soil P mining and soil degradation. Alleviating current environmental concerns and addressing the need for resource conservation, whilst meeting the food demands of a rapidly expanding population, requires new long-term strategies to drive more efficient and sustainable use of P.

Strategies towards long-term sustainability in P use have centred on the 4Rs – Reduce demand (imports), Recycle manures and wastes, Re-use recovered P products and Re-define the food chain. Recent scenario analysis at the global scale suggests recycling manure P and better integration of livestock and cropping systems is the most effective way to use less P fertiliser and these goals are consistent with the philosophy of relying more on biological regulation to manage agroecosystems at field, farm and landscape scales rather than continuing to rely on large chemical inputs; the concepts of ecological intensification, sustainable intensification and integrated production. Substance flow analysis has clearly demonstrated the regional scope to close the P cycle; for example surpluses varied by a factor of 3 across 21 regions of France with greatest surpluses on livestock farms. In most countries around the Baltic Sea, mean soil P balances are close to zero (+1–+2 kg P ha⁻¹ year⁻¹), but single fields in Sweden have shown P balances between -5 and +5 (kg P ha⁻¹ year⁻¹) and accelerated dissolved reactive P concentrations in drainage water (1988–2009) where the field P loading is accelerated.

There are now a number of favourable policy drivers encouraging manure recycling and the range of organic materials being applied to land has increased considerably in recent years and will continue to do as nutrient recovery and treatment technologies become more sophisticated. Manures are also now valued more highly as a nutrient source because of the increasing costs of inorganic fertilisers and give well-recognised added benefits to soil and crop quality. Variability in composition, difficulties in handling and low confidence in nutrient release patterns must be overcome to enable their better integration into cropping systems. More knowledge is needed, but also methods for transferring this knowledge into sustainable farming practices, through farmer-friendly advisory tools and

incentive schemes. In all kinds of soils, manures stimulate microbial activity and mobilization of soil P. This is especially important for clay soils where soil aggregates may be strengthened and the soil structure improved, possibly leading to reduced soil P erosion.

Current management of manures on farms is geared around nitrogen (N) and their application leads to soil P accumulation and increased transport of soil P in runoff and leachate. Adoption of P-based management criteria (either as a surplus or soil P limit) are highly effective in reducing the risk. However, they confound the philosophy behind recycling a valuable resource by limiting the landbank available to receive manures, especially on livestock farms where soil P contents are already high due to oversupply of P. Overcoming issues of manure transportability must be a key objective for improving sustainable P use. Greater precision in meeting livestock P requirements will help to increase P use efficiency and reduce manure P loadings to land, especially for non-ruminants who lack the phytase enzyme. Direct losses of P in runoff following manure application are still a concern but can be largely overcome by careful management; e.g. rapid incorporation, which is also very important for reducing ammonia emissions. Field studies have demonstrated the importance of best management practices for applying manure e.g. when ending fallow and incorporation of leys. Improving manure quality, public perception of manures and providing more flexible legislation to allow use of recovered materials are also needed to facilitate long-term change.

Cropping systems and associated soil management influence P management through their varied ability to capture and mine soil and applied P and reduce the risk of soil erosion and runoff. Modern crop varieties have been bred to perform in high P environments and no longer need the innate mechanisms they possess for scavenging for P in low P environments. However the need to maintain high soil P environments is increasingly being questioned on both economic and environmental grounds. Developing robust techniques to farm profitably on soils with reduced P availability (low P soils) and utilize any legacy P more effectively would help to improve food security in developing nations and improve the sustainability of agriculture in developed countries. Strategies for farming on low P soils require greater understanding of the relative importance of root architecture and crop-soil rhizosphere interactions for nutrient cycling and links to crop management (e.g. intercropping). There is certainly sufficient genetic variation in plant traits for soil P acquisition to suggest there is scope to modify cropping systems to perform better in low P soils and also reduce erosion.

Cover crops, crop residue and green manure management play an important role in reducing particulate P transport, but more precise management is needed to overcome the increased risks of P leaching associated with some practices. Crop cover during autumn and winter is also of major importance for reducing N leaching. Different types of cover crops (grasses, legumes, brassica species and phacelia) may be grown, and in Poland recommendations have been developed for different soil fertility. Trade-offs between reducing particulate P (PP) loadings and increasing dissolved P loadings in runoff associated with adoption of conservation tillage remain an issue for water quality. For some sites there is no P benefit from reduced tillage as was demonstrated in a Swedish study of a clay soil, where PP leaching losses down macropores were on average 0.12 kg ha⁻¹ year⁻¹ greater from reduced tillage than from conventionally ploughed treatments over a six-year period.

Landscape management offers potential solutions to these issues by matching cropping systems and manure management to those areas that are best suited to production goals and to cope with the environmental risks. Long-term sustainability of P use requires strategic answers to manure and crop management at the regional and country scale in addition to the implementation of improved field and farm-based management options. Phosphorus use and management must also not be consid-

ered in isolation but must be integrated with other drivers to improve resource utilization efficiency (e.g. N) and the environmental footprint of agriculture (e.g. green-house gas emissions and use of herbicides and pesticides). Cover crops or intercropping provide multiple benefits in reduced nutrient losses, improved soil fertility and soil structure, which are all necessary for a more sustainable agriculture.

Further investment in precision farming and genetic engineering for both the livestock and cropping sectors is needed to ensure more exact matching of inputs to demand and enable more efficient use of soil and applied P. Spatial disconnects between livestock and cropping areas remain a major barrier that requires technological innovation to allow easier transportation of high value P products across regional boundaries. Landscape management offers real opportunities to tailor manure and cropping system management to reduce P loads delivered to rivers. Farm- and landscape models will continue to be important in analysing the trade-offs between crop and manure management scenarios to ensure that practices that are sustainable for P are also sustainable for other ecosystem services.

CHANGES OF SOIL FERTILITY PARAMETERS AND NUTRIENT BALANCE IN THE IRRIGATED AREA OF SOUTHERN LOESS PLATEAU, CHINA

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Better understanding of soil fertility and nutrient balance in soil–crop systems are important for rational fertilization, refining agricultural management practices and improving water and soil resources utilization efficiency. This study addressed the temporal variability of soil organic matter (OM), total nitrogen (TN), available nitrogen (AN), available phosphorus (AP), and available potassium (AK) in the irrigated area of southern loess plateau, China from 1980s to 2010-2012 using geostatistical method. Over 30 years, OM, TN, AN, AP and AK in soil increased by 48%, 12%, 50%, 197% and 20%, respectively. N and AP was surplus in the soil, while AK was depleted based on the calculation of the gaps between the inputs and uptake in winter wheat-summer maize rotation system in different periods (1986-1990, 1991-2000 and 2005-2009) based on the household survey and this pattern displayed upward trends with time. Nutrient balance status at present condition in this area was evaluated using the estimated model of nutrient permissible surplus or deficit rate, and it indicated that N and P practical surplus rates were 114 and 75 percentage points higher than their permissible surplus rates, respectively, indicating that N and P surpluses in this area greatly exceeded their rational ranges. K practical deficit rate, 5.0 percentage points higher than its permissible deficit rate, was within the permissible scope. Numerous long-term fertilization experiments which set up at the end of 1980's to monitor changes in soil fertility with application of either inorganic fertilizers or organic manure alone or a mixed application of both proved rational fertilization is an important measure of maintaining soil fertility. It is suggested soil nutrients inputs of N and P in this study area should be reduced, and that of K should be increased to keep the high and stable yield of crops and reduce environmental risk caused by excessive fertilization.

LONG TERM EFFECT OF VARIOUS FERTILIZING STRATEGIES ON SOIL ORGANIC CARBON, CROP YIELD, SOIL P AVAILABILITY & POTENTIAL P LEACHING

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In 2005, a field experiment with arable and vegetable crops was started on a sandy loam soil. The experiment compares 8 fertilizer treatments: MIN (mineral fertilizers), FYM (farmyard manure), CSL (cattle slurry), VFG (vegetable, fruit and garden waste compost), CMC1 (farm compost, high C/N), CMC2 (farm compost, low C/N), NF+ (no fertilizer) and NF- (fallow). The slurry addition rate in the CSL treatment is yearly calculated using the N balance method. The other organic fertilizer treatments are normalized for C input (2-3 Mg C/ha.yr) with the CSL treatment. Extra mineral NPK is applied to equalize between treatments for plant available N, 100 kg P₂O₅/ha.yr and 300 kg K₂O/ha.yr. During the course of the field trial crop yields were measured. In 2011 and 2012 TOC (total organic carbon), P availability (0.01M CaCl₂), potential plant available P (ammonium lactate, pH 3.75) and P export were measured. In 2011 a soil column laboratory experiment was conducted, to investigate potential P leaching from the top soil (0-30 cm). For every year the dry matter (DM) crop yield was calculated relative to the mean DM crop yield of all fertilized treatments. Calculated over the entire period (2005-2013), the relative DM crop yield was CSL^a (94)<MIN^a (94)<CMC1^{ab} (100)<FYM^{ab} (103)<VFG^{ab} (104)<CMC2^b (106). Although C input was equal in all organic treatments, there was a clear effect of carbon source on the TOC content: VFG (1.32%)>CMC2 (1.27%)>FYM (1.24%)>CMC1 (1.21%)>CSL (1.13%)>NF+ (1.05%)>MIN (1.03%)>NF- (0.97%). The P availability in the FYM treatment was clearly higher compared to all other treatments. However, this effect was not always significant. No significant differences were found in potential plant available P and P export between the fertilized treatments. The leaching experiment revealed a significantly higher (p<0.05) total P leaching potential for the FYM treatment compared to the other treatments. The speciation of the total leached P was not influenced by the fertilizer treatments. Approximately, 80-90% and 45-60% leached as total dissolved P and ortho-P, respectively.

In conclusion, only the application of farm yard manure resulted in enhanced P availability levels, while this did not lead to significantly higher DM crop yield or P export. For the organic fertilizers applied, an increase of the potential P leaching has been observed only for FYM.

LONG TERM IMPACT OF TILLAGE PRACTICES AND P FERTILIZATION ON SOIL P FORMS AS DETERMINED BY ³¹P-NMR

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A better understanding of organic phosphorus (P) transformations is needed to improve management of phosphorus fertilization and tillage. Conservation tillage practices have become increasingly common in recent years to reduce soil erosion, improve water conservation, and increase soil organic matter. However, the effects on soil properties, especially phosphorus (P) forms, amounts and distribution in the soil profile remain largely unknown. This study was conducted to assess the long term effects of tillage practices (no till [NT] and mouldboard plowing to 20 cm depth, [MP]), and P fertilization on P composition and distribution in the soil profile. The long term corn-soybean rotation experiment was established in 1992 on a deep clay loam soil of the St-Blaise series (Dark Grey Gleysol) in l'Acadie, Quebec, Canada. The experimental design was a split plot with NT and MP assigned to main plots and nine combinations of three P (0, [P₀], 17.5 [P_{17.5}], and 35 [P₃₅] kg P ha⁻¹) and three N (0, 80, and 160 kg N ha⁻¹) additions assigned to subplots. Only the plots with the P₀ and P₃₅ treatment combined with 160 kg N ha⁻¹ were considered in this study. We used 36 air-dried soil samples collected from three depths (0-5, 5-10, and 10-20 cm). These were analysed for Mehlich 3 P (PM3) and with solution phosphorus-31 nuclear magnetic resonance spectroscopy (³¹P-NMR). Greater surface (0 – 5 cm) PM3 and inorganic orthophosphate concentration in NT-P₃₅ soils compared to the deep layer (5 – 20 cm) indicated a stratification of inorganic P. Organic P stratification was shown with orthophosphates diesters at the 0 – 10 cm depth of NT-P₃₅ treatment, whereas the orthophosphate monoesters were accumulated in the deep layer (10 – 20 cm) presumably due to preferential movement. This P stratification appeared to be caused by a lack of mixing of fertilizer, crop residues and soil. We concluded that additions of P fertilizer in NT systems increased the potential for P loss in runoff at this site.

MANAGING LEGACY SOIL PHOSPHORUS TO SUSTAIN AGRICULTURE AND PROTECT WATER QUALITY

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A central tenet of modern nutrient management planning is the need to maintain soil phosphorus (P) in a range that optimizes crop production and protects water quality. Decades of research have identified the soil test P (STP) critical values needed for economically optimum crop yields, leading to well-established recommendations for efficient use of inorganic and organic P sources as soil amendments. However, in many areas of the USA and other countries, long-term over-application of animal manures and fertilizers has led to soil P accumulations to values that are considerably above agronomic optima and of concern for surface water quality. These soil P accumulations are a legacy of historically inefficient P management and present serious challenges to our efforts today to prevent nonpoint P pollution of surface waters. The fundamental issue identified in most research has been that it can take years, even decades, to decrease soil P values from “excessive” to “optimum”. Thus, even if P inputs to “high P” soils are restricted or eliminated, environmentally significant P losses to water may continue. For example, in Delaware, statewide summaries show ~60% of soils tested have STP values more than twice the critical value (~30 mg P kg⁻¹, Mehlich 3 soil test); in the intensive poultry producing regions, >30% of soils have STP values more than six times the critical value. A recent long-term (11 yr) cropping (corn-soy) study we conducted at two sites that had initial Mehlich 3 P values of 98 and 70 mg kg⁻¹ found that ceasing P applications decreased STP by 43% and 27%, with no negative effects on crop yields, providing guidance for emerging strategies for management of “high P” soils. Although similar long-term studies are somewhat rare, we have analyzed the findings of > 25 studies from the US and Europe investigating the relationship between P management, cropping system, and changes in amount and form of P in “high P” soils. Our presentation summarizes the findings of long-term P depletion studies in Delaware and our quantitative analyses of similar studies conducted in settings varying in initial STP, soil type, cropping system, and climate. We present strategies and policies to address the “legacy” P issue in over-fertilized soils, toward a goal of sustaining soil P values in ranges optimum for crop production and protection of water quality.

Theme 5

ORAL PRESENTATIONS

Identification of appropriate mitigation measures for reduction of P losses – efficient use of existing techniques and development of new methods



Keynote lecture:

IDENTIFICATION OF APPROPRIATE MITIGATION MEASURES FOR REDUCTION OF P LOSSES – ARE CHEMICAL METHODS A VIABLE OPTION TO CURB P LOSSES DURING THE TRANSPORT PHASE?

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Sensible applications of P fertilizers and other P sources, as well as preservation of soil structure for erosion control are the first-priority measures for moderation of P losses from agricultural soils. Good advices easily given, but in the everyday life in farms these targets are sometimes compromised. Excessive P inputs and high soil test P concentrations are frequently found in animal farms that are also susceptible for “incidental” P losses associated with manure storage and handling, or from exercise yards and ensilage storages.

In addition to adjustments in the tillage practices P mobilization from erosion prone or high-P soils can be modified by different types of chemical amendments, such as polyacrylamides (PAM), gypsum, or quick lime to increase infiltration and decrease P solubilization to runoff. For P that has already reached ditches with runoff and subsurface drainage waters, sediment (particulate P) settling can be enhanced, by e.g. wetlands of sufficiently long residence time. However, wetlands are inefficient in coping with dissolved P outside the growing season. In many regions it is the time when the discharges, and thus P transports, are at their highest.

For capturing dissolved P with chemicals during the transport there are two main options: soluble substances that dissolve in water and strip P from the water column as a precipitate, or solid media that bind P on the reactive surfaces. The first approach includes application of metal salts such as ferric or aluminium sulphates and chlorides. The second approach, solid P sequesters, may involve materials originating from, for example, side flows of industrial or mining operations.

Soluble metal salts can be regarded as a proven option to bind P, as they have been for decades used in water and wastewater purification plants. In water treatment plants stripping of P (and solid matter) can be fully optimized, and settling and removal of the sludge is relatively easily arranged – unlike in small units that could be placed in field ditches. Nevertheless, there are examples of simple, small-scale units that, by feeding e.g. ferric sulphate in runoffs, may effectively decrease the concentration of dissolved P in runoff (Närvänen et al., 2008). The core idea is to bind dissolved P in a form that is sparsely available for aquatic organisms and by that way suppress the growth of algae and other biomass in the receiving waters. Meanwhile the P bound, for example as Fe-P association, remains in the water system and settles to the sediments of the treated ditches, or later in water bodies. Whether the burial is permanent or not depends on the nature of the precipitate, specifically its tendency to dissolve in the new environment.

In principle, a construction with a solid P retention media that has a high retention capacity would be an ideal solution for P mitigation during the transport. Such a solution would not need much maintenance other than changing the retention media at intervals. Further, P collected from water would be preserved inside the structure for possible recycling, and potential risks associated with handling and use would be much smaller as compared to the use of soluble chemicals. Out in the field, however, solid surfaces may soon become covered with biofilms or by accumulation of organic molecules. Once the surfaces of the solid P retention media become covered, there is no direct contact between the reactive surfaces and water, and P retention ceases. Clogging of pore volume due to retention of soil matter, as example, or material alterations with time may lead to changes in hydraulic properties of the material bed and formation of preferential flow paths. Preferential flows decimate residence time of water in the material bed, and dead zones cannot contribute to P retention even if there would be much retention capacity unused.

The mechanism of P retention by solid media also matters. Materials that retain P by e.g. Ca-phosphate precipitation, by necessity release Ca^{2+} and OH^- ions in the water phase. The release of these ions is regulated by the volume of water, instead of being controlled by the delivery of P to the material. Hence, flows that are low in dissolved P concentration may deplete the stock of soluble ions and eat up the P retention capacity before the material does the job it was intended for (see e.g. Klimeski et al., 2012).

The economy of chemical methods is likely to be the main restriction in their wide use. To work at high efficiency, they must be applied at sites with high dissolved P concentrations. For streams characterized by more dilute waters, the only sensible option is to turn focus to the source and keep P applications at sensible levels and apply those techniques that minimize the P mobilization from the soils.

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Klimeski, A., Chardon, W.J., Turtola, E., Uusitalo, R. 2012. Potential and limitations of phosphate retention media in water protection: A process-based review of laboratory and field-scale tests. Agric. Food Sci. 21 (3): 206-223.

GYPSUM AMENDMENT OF SOILS AS A MITIGATION MEASURE FOR REDUCTION OF PHOSPHORUS LOSSES IN AN AGRICULTURAL CATCHMENT – EFFECTS AND DURATION

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Unless nutrient loading from agriculture is drastically reduced, many water bodies in Finland will not achieve the good ecological state demanded by the Water Framework Directive by 2015. We estimated the changes in the losses of particulate and dissolved P and turbidity after treating 93 ha of agricultural field with gypsum (4 t ha⁻¹) in a 245 ha catchment in southern Finland. Runoff was monitored using online sensors and manual sampling during one high-flow period before and nine periods after the gypsum amendment. Turbidity recorded by the sensors correlated well with the concentrations of particulate P analysed in the laboratory, which enabled the evaluation of changes in particulate P from the online data. Gypsum amendment performed in autumn 2008 immediately decreased the losses of suspended solids, P and turbidity from the catchment. The effect lasted at least four years. Using a covariance model, gypsum amendment was estimated to have reduced the loss of particulate P by approximately 54 %. The loss of dissolved reactive P appeared to decrease by one quarter, but was estimated with less precision. No such changes were found during the same period in a nearby ‘reference’ catchment, where gypsum was not used. Gypsum did not affect soil test values for pH, P, K, Mg or Ca, but it did increase the ionic strength and soil test SO₄ significantly. In addition, soil test values for Mg increased in sub-surface soil.

Now after five years of gypsum application, P losses may still be lower than before the gypsum amendment, if evaluation is based on the observed catchment data. However, if the data are compared to those in the ‘reference’ catchment, no gypsum effect can anymore be seen. Soil analyses in the observed catchment show no more effect of gypsum either, and with the aid of the correlation between SO₄ concentration and electrical conductivity in the runoff, approximately 79% of gypsum was estimated to be lost by the end of the year 2012. In clayey catchments discharging into the sea, gypsum may provide an efficient means to reduce P losses from field cultivation particularly at high risk sites but the impact of SO₄ associated with gypsum amendment on the ecology of rivers and lakes has yet to be determined.

IMPACT OF BIOCHAR AMENDMENT ON PHOSPHORUS RETENTION BY RIPARIAN SOIL

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Establishment of riparian zones have the potential to reduce the effects of diffuse discharges of nutrients into waterways. Addition of biochar to soils in a riparian zone may improve the nutrient removal efficiency and extend the life of the riparian zone while sequestering carbon. The ability of biochar to improve phosphorus (P) retention in a simulated riparian zone was investigated by adding 30 t ha⁻¹ of *Pinus radiata* biochar (pyrolysis temperature 350°C) to a Templeton Silt Loam soil and planted with a commonly used riparian zone New Zealand native, *Carex secta*. Four replicates of four different treatments were established in simulated riparian strip biotrons comprised of plastic-lined wooden boxes (20 cm x 12.5 cm x 150 cm; gradient 1:3.25), which were maintained in a controlled environment (glasshouse) over a period of 7 months. Treatments included a control (WNC), biochar amendment (WBC), nutrient amendment as dairy shed effluent (ENC), and combined biochar-nutrient amendment (EBC). Water (17mm) was applied to the control and biochar treatments on 5 occasions over 6 months to induce repeated drainage events, while the same quantity of diluted effluent was applied to the nutrient and biochar-nutrient treatments. The total quantity of P applied in diluted effluent was equivalent to 100kg ha⁻¹. Subsurface drainage was collected after each irrigation event for P analysis, and plant biomass was harvested at the end of the experiment. Phosphorus loss in drainage was very low from the control treatment, and this was not affected by biochar amendment. As expected, the addition of nutrients significantly increased plant growth and loss of P in subsurface drainage. However, the presence of biochar resulted in a significant 35% decrease in the total P loss in subsurface drainage, which was mainly attributed to reduced macropore flow and enhanced microbial immobilization.

SORBENTS FOR PHOSPHATE REMOVAL FROM AGRICULTURAL DRAINAGE WATER

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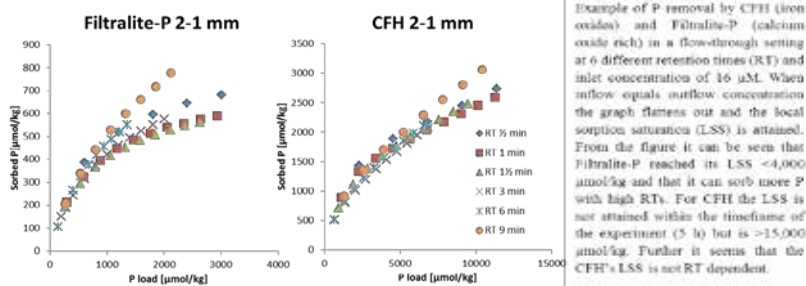
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Subsurface transport of phosphate (P) from fertilized agricultural fields to freshwaters may lead to eutrophication and reduced biodiversity in inland waters. Mitigation of eutrophic waters is difficult and costly. Reduction of P export to surface waters using filters installed in agricultural drains comprising P sorbing materials (PSM) may be a more efficient and cost-effective way to improve water quality. Several materials have been proposed as PSMs for use for cleaning agricultural drainage water. The objective of the present study was to provide data on sorption behavior among a variety of PSMs in order to select a material that can quickly remove P from runoff water at both base and peak flow. This was performed by screening 15 “local” PSMs’ for their ability to sorb low orthophosphate concentrations (0–161 μM) at short equilibration time (<24 min) in a batch set-up. Further, the P-loaded PSMs’ ability to release previously sorbed P was tested. The two best performing PSMs (Filtralite-P and CFH-12) in two particle sizes were further tested in a flow-through setting. In these latter experiments four inflow P concentrations of 1.6 and 3.2 μM (representing base flow) and 16 and 32 μM (representing peak flow) were all tested with 6 different retention times ranging from $\frac{1}{2}$ to 9 min. In order to test the PSMs’ ability to retain the sorbed P, all sorption experiments were followed by desorption using P-free artificial drain water.

These studies clearly show that iron oxide-based CFH is superior to the other PSMs examined in this study, considering both P affinity, sorption kinetics, and P retention. CFH reacts fast, removes more P, and retains P with greater strength as indicated by lack of desorption (less than 10% for batch and flow through). Further, CFH was effective at low P concentrations and was less dependent on retention time, pH, and solution composition compared to the Ca-based PSMs.



PHOSPHORUS SATURATION IN RIPARIAN BUFFER STRIPS

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There remain many unanswered questions on the functioning and efficiency of buffer strips for phosphorus (P), including their effectiveness over time. This is important because buffers which have accrued P could themselves potentially become a source of P via erosion or remobilisation of sorbed P. We investigated the relationship between buffer age and soil P adsorption characteristics in twelve riparian buffer strips across the three catchments included in the UK Defra Demonstration Test Catchments Project, namely the Eden, Wensum and Hampshire Avon catchments. Four sites with similar properties (e.g. soils, slopes, land use) with buffers of comparable widths but different ages were selected in each catchment. Soil samples from the upslope fields and across the buffer strips were collected in both summer 2010 and winter 2010/11 and analysed for a range of parameters including different forms of P. Our hypothesis was that the capacity for retention of P in buffer strips by subsurface adsorption in soils would vary depending upon the age of the buffer, with older buffer strips being more saturated than younger ones.

There was some evidence that buffer age affected P status, but only in the Eden catchment where a significant relationship occurred ($p < 0.01$) between degree of P saturation (DPS, defined as the ratio of the amount of P sorbed in the soil and the finite capacity of a soil to sorb P) and buffer age in both summer and winter, DPS being greater in the older buffer strips. The DPS of almost all buffers in all catchments was ca. <50%, and it never exceeded 77% suggesting that once soil equilibrium with P solution has been met, desorption of P may occur. Winter DPS values were significantly higher ($p < 0.001$) than in summer in all catchments. We speculate whether this reflects a gradual accumulation of P in the buffer soils, or a scenario in which desorption processes were dominant in summer and adsorption processes were more prevalent in winter. This possible seasonal recharge- discharge scenario could play an important role in the functioning of buffers with regard to P dynamics because, although in its simplest terms it may mean that the buffer is not acting as a 'permanent' store of P, it could be an important regulator of P fluxes at critical times. This possible cycling/regulating of P warrants further investigation.

Theme 6

ORAL PRESENTATIONS

Implementation of mitigation strategies to reduce P losses – how can we get the farmer to use the most appropriate BMPs?



Keynote lecture:

IMPLEMENTATION OF AGRICULTURAL PHOSPHORUS MANAGEMENT TO PROTECT WATER QUALITY – LESSONS UNDER VOLUNTARY AND REGULATED ADOPTION

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The challenges of mitigating diffuse phosphorus (P) pollution are manifold, but no more complex than in the arena of implementing P-based management in agricultural systems. Phosphorus-based practices and strategies considered novel in the 1990s have now been implemented across North America and Europe, providing a wealth of experience. While common obstacles to P-based management implementation exist, the nature of these obstacles shifts with the extent to which adoption is driven by regulation, and, obviously, by the differences in socio-economic and physiographic settings. We seek to draw upon a breadth of P management experience in U.S., U.K., and Sweden, to highlight both the challenges and opportunities.

The Chesapeake Bay is the largest estuary in the U.S. with by far the largest catchment to water surface area ratio of any other waterbody in the world, which complicates targeting of appropriate conservation measures to mitigate water quality concerns. A much publicized deterioration of Bay water quality in the 1990's has led to numerous and extensive conservation initiatives. High concentrations of livestock in some areas of the Bay Watershed have made manure management a priority water quality concern, with a variety of manure application practices advocated. These practices place manure below the surface of the soil, protecting against incidental transfers of manure nutrients, especially P, in surface runoff. Incentive programs to increase adoption of these practices have been chronically undersubscribed, and local projects aimed at transferring these manure applicators to farmers have seen interest, but little adoption. Price, and, more importantly, time management, appears to be major factors behind this resistance. Other concerns include compatibility with planting equipment (many applicators leave ridges in the soil that affect seed/soil contact), and limitations in terms of when these applicators may be used. Unless verifiable progress in adoption of these and other measures to reduce nutrient runoff occurs, the call for more regulated management of farming will increase. Unfortunately, we have seen this scenario in other regions of the U.S., lead to increased polarization of interests and more passionate finger pointing, which has the unfortunate consequence of slowing progress and the adoption of science-based solutions.

The New York City Watershed Agriculture Program (NYCWAP) has been widely touted for its success in tackling P-based eutrophication in its principal agricultural catchment. Using a voluntary program based upon whole farm planning, the NYCWAP implemented practices

ranging from barnyards, calf greenhouses and nutrient management planning, but faced considerable resistance when it came to one of the foundations of pasture-based conservation and nutrient management: stream-bank fencing. Despite considerable incentive programs, farmers were unwilling to accept the practice for a variety of reasons, ranging from maintenance to management preference to aesthetics. However, a program to document the contribution of cattle with access to stream provided quantitative evidence of the impact on catchment P load. As a result of this knowledge, voluntary adoption not only improved, but the farmer-based NYCWAP opted to mandate that stream-bank fencing be included in whole farm plans. However, similar efforts in other parts of the country (i.e., southern plains grazing lands of Arkansas - AR and Oklahoma - OK) to encourage exclusion of pasture-grazing beef cattle from streams with fencing, was met with vehement opposition by farmers.

The Illinois River and Eucha-Spavinaw Watersheds span the states of AR and OK and has been the focus of litigation aimed at improving the health of the river. A rapid five-fold increase in the population in Northwest AR over the last 20 years has coincided with the expansion of confined poultry broiler operations, which now produce over 2 billion birds annually, nearly 25% of the total broiler production in the US. The U.S. Environmental Protection Agency has ruled that upstream catchment users are responsible for downstream water quality. To move litigation forward to settlement, the presiding Judge adopted the best science to manage manure based on P using the site assessment tool, the P Index, such that any application of P had to be based on there not being a high risk of loss in runoff. However, the Judge included an additional arbitrary soil P threshold to further limit applications (no P to be applied when Mehlich-3 P is $>150 \text{ mg kg}^{-1}$). These regulatory programs have led to a decrease in the rates of litter applied in the catchments (from ~ 100 to $40 \text{ kg P ha}^{-1} \text{ yr}^{-1}$) and to the development of the only viable manure export program in the U.S., such that over 80% of the manure produced in the Eucha-Spavinaw Watershed is now exported out of the catchment. The poultry growers eventually adapted to these regulations with some subsidies, but those paying the real price of this litigation are the beef farmers who had benefited from a cheap and plentiful source of nitrogen (N) for area pastures that allowed them to profitable rear more cattle on the acreage. Thus, an indirect consequence of the litigation has been a slow decrease in herd size, pasture productivity, and the potential for increased erosion.

Diffuse P pollution in the UK accounts for between 6 and 50% of total P loadings to surface waters depending on the region. Measures to reduce P loadings have largely focused on voluntary initiatives incentivized by countryside stewardship schemes linked to general EU cross-compliance measures introduced to protect soil and water quality. Only in Northern Ireland is there a specific regulatory requirement under the Nitrates Directive not to exceed a farm P surplus of $10 \text{ kg P ha}^{-1} \text{ yr}^{-1}$ and this currently only applies to a relatively small number of derogated farms. A large number of stakeholder-led catchment-wide action plans have been initiated across the UK to help reduce diffuse P loadings. For example, the success of a full stakeholder participatory approach to site risk evaluation and identification of cost-effective and acceptable measures has recently been demonstrated in the Lough Melvin catchment in Northern Ireland. Lough Melvin is a high value lake suffering from P loadings in land runoff even though the farming is low intensity.

The 5-year England Catchment Sensitive Farming Delivery Initiative recently reported that farmer uptake of advice and farmer specific recommendations to reduce diffuse pollution has been over 50% with expected reductions in P loadings predicted by models. However, while farmers are becoming increasingly aware of the problems, catchment uptake of measures at a sufficient intensity to improve water quality has yet to be demonstrated. The River Tarlund Catchment Initiative in Scotland has so far failed to demonstrate any effect of installed buffer strips on either water chemistry or stream ecological quality. Attempts to demonstrate positive outcomes from farmer-friendly farming are also being confounded in many areas by discharges from rural point sources. In some instances, farmers breaching cross-compliance rules (e.g., exceeding P-based nutrient guidelines) have been fined and further strengthening of these rules is already underway to prevent poor practice.

In northern Europe, the Baltic Sea is another water body suffering from an unacceptably high nutrient load leading to severe outbreaks of algal bloom. In 2006, an international expert group reported that phosphorus is the main cause for eutrophication and that agriculture accounts for 40-50 % of the total Swedish anthropogenic P input. Similar findings have been made for other countries around the Baltic Sea. In response to this situation, the European Commission and the environmental ministers in countries around the Baltic Sea adopted a joint action plan in 2007, the Baltic Sea Action Plan (BSAP), with the aim of achieving good environmental status by year 2021. The commitments under BSAP are different in different countries, to a large extent based on their current status. In Sweden, separate action programs have been developed in response to this plan to reduce P, and also N losses from the agricultural sector, which includes legislative rules on the storing and spreading of animal manure, financial instruments such as environmental compensatory payments and tax on mineral fertilizers, and information activities within the program 'Focus on Nutrients'. These action programs intend to put the measures into practice within the agricultural sector.

Since 2000, there are subsidies available within the Swedish Rural Development Program, which is partly funded by the EU, to compensate farmers for carrying out certain measures to reduce P losses. Such measures entitled to subsidies include buffer zones for land prone to erosion, sedimentation ponds (constructed wetlands), and organic crop production. During the period 2000-2006, Swedish farmers received about 3 million USD yr⁻¹ in subsidies for buffer zones that are estimated to reduce P loads by 6 tons yr⁻¹. In other words, the cost to reduce the load by 1 kg P was about 500 USD. The conclusion in a recent evaluation of measures within the Rural Development Program to reduce agricultural non-point source pollution was that specific measures (e.g. buffer zones) to solve specific problems (e.g. runoff losses of P) were much more cost effective than subsidizing farming concepts such as organic crop production.

THE EFFECTS OF CONSERVATION PRACTICES ON PHOSPHORUS LOSSES FROM ROW CROP AGRICULTURE IN THE ST. JOSEPH RIVER WATERSHED, USA

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Conservation efforts in the US have focused extensively on decreasing phosphorus loadings from fields in the last ten to twenty years. In the St. Joseph River watershed, the effects of conservation practices on nutrient loadings have been observed through an extensive water quality monitoring network. Conservation practices that have been tested in fields where monitoring occurs include: grassed waterways, blind inlets, conservation tillage (zero tillage and rotational tillage), and conservation rotation (crop rotations with more variety than corn and soybean). Surface runoff and tile discharge are monitored in these fields. In these fields, between 35 and 80% of the soluble and total phosphorus loading occurs through the subsurface tile network, which is greater than what many other researchers have observed. The conservation crop rotation appears to generally have lower nutrient losses than the more common corn/soybean rotation. Zero tillage results in less total phosphorus loading than tilled fields, however there is generally more soluble phosphorus loading from the zero tillage field. The grassed waterways appear to reduce phosphorus losses predominately as a function of reducing sediment loads. While conservation practices are generally deployed to affect a single resource concern (i.e. erosion), there may be unintended consequences of increasing the loading of other contaminants (i.e. soluble P). However, given the suite of practices employed within this watershed, they can and do work in concert to reduce phosphorus loading below what could otherwise be expected.

IMPLEMENTATION AND VERIFICATION OF BMPs TO REDUCE FARM P LOADS: A LONG-TERM COLLABORATIVE EFFORT

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The Everglades Agricultural Area (EAA) consists of a portion of the original Everglades region of south Florida, USA, which was artificially drained to sustain an annual \$2 billion agriculture farming industry within the region. To maintain the high rate of productivity, nutrient and water management is essential. However, the delivery of excess phosphorus (P) has been described as a major cause of eutrophication and ecosystem imbalances to the Everglades. A mandatory Best Management Practice (BMP) program was implemented on the EAA farms in 1995 as required by the Everglades Forever Act to reduce P loads from drainage waters that enter the Everglades ecosystem. All farms in the EAA basin implement mandatory BMPs. The main objective of the program was to reduce P loads from the EAA basin by 25% or greater compared to a ten-year pre-BMP baseline period. The program focuses on improving water quality exiting EAA farms canals by (i) implementing and verifying BMPs for reducing P loads, and (ii) through continuing educational BMP seminars and training workshops. Growers are credited by points for implementing various BMPs on their farms. The BMPs are divided into three basic categories consisting of water management, nutrient management, and sediment controls. Two BMPs commonly employed by most EAA growers are soil testing and banding of P fertilizer. The EAA basin P load reduction has averaged > 50% yearly since the BMP program's inception. In 2012, the total P (TP) load reduction was 71% corresponding to a flow weighted mean TP concentration of 93 ppb exiting the EAA, attesting to the success of the partnership between the EAA growers, South Florida Water Management District, and University personnel. Differences in P load reduction exist between farms and sub-basins due to differences in cropping and management systems, and environmental factors.

IDENTIFYING P LOSS RISK AND APPROPRIATE MITIGATION MEASURES AT FARM LEVEL IN CO-OPERATION BETWEEN FARMERS AND AGRICULTURAL ADVISERS

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In the project ‘Focus on Phosphorus’ farmers, agricultural advisers, researchers and authorities co-operate in order to find effective strategies to reduce P losses from agricultural land to waters. Within the project, which started in 2007, both established and new mitigation measures were implemented. The project is run in three small agricultural catchments where nitrogen and phosphorus discharge at stream outlets has been measured for at least 10 years before introducing the mitigation measures. In order to further involve the farmers a questionnaire matrix was developed within the project in 2012. The questionnaire matrix put together recent knowledge on risk sources for P loss to waters and corresponding possible mitigation measures in regard to: (1) cropping systems including soil tillage and fertilization; (2) in-field characteristics including soil properties and function of drainage systems; and (3) character of ditches and watercourses. Additionally, an erosion risk map identifying surface runoff and ponded water was developed based on high-resolution elevation data and a distributed model (USPED). When both the matrix and the erosion map were used, we found that in one catchment just a few high risks remained after the intensive advice and mitigation measure campaign the previous years. In this catchment measures as structure liming, buffer-zones and reduced soil tillage were already implemented to a great extent, and at the stream outlet P losses were significantly reduced after the implementations. In the two other catchments, risk factors such as reduced capacity in drainage systems, soil compaction and stream bank erosion were identified to be important. The questionnaire matrix together with the high-resolution erosion map may become a widely used practical tool for the farmer to identify risk areas and appropriate mitigation measures at farm level, preferably together with an adviser. If many low-cost measures can be found and implemented, the total reduction in P losses can be important at national scale. Having the farmers own knowledge and experience as the driving force in finding the risk sources and adequate measures is probably a most effective approach in reducing P losses.

THE COMPARATIVE COST EFFICIENCY OF THREE BUFFER ZONE PROGRAMS TO REDUCE PHOSPHORUS LOSSES IN A SMALL SWEDISH CATCHMENT

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Riparian buffer zones are the only measure which has been used extensively in Sweden to reduce phosphorus losses from agricultural land. Implementation of riparian buffer zones in Sweden has been supported by payments to landowners from the EU Rural Development Program (RDP). These payments have been a uniform reimbursement per hectare for buffer zones from 6-20 meters wide for a five year commitment in eligible areas. The purpose of this study is to compare the cost efficiency of alternative programs for implementation of buffer zones. To illustrate how different allocations of measures effect cost efficiency three allocation scenarios in the Svärtaå catchment, located in central Sweden south of Stockholm draining to the Baltic Sea, were estimated with information from the Swedish buffer zone cost data base FyrisSKZ. The baseline scenario in the study uses the actual distribution of buffer zones from 2008 and combines the average effect of buffer zones used for calculation of the Helcom PLC5 data (10 meters wide). The second scenario allocates a six meter wide buffer zone on all the potential area in each sub-catchment. Potential area is based on the requirements for buffer zones along watercourses as defined in the Swedish RDP. The third scenario allocates areas of buffer zones (widths) to sub-catchments based on the average cost of reduction. The average cost per unit of reduction for the baseline scenario is € 321/kg P. Although the total P reduction is reduced by 20% in Scenario 2 compared to the baseline scenario, the average reduction per hectare increases by 40% and the cost effectiveness shows almost a 30% improvement. In the third scenario cost efficiency increases the most (to € 209/kg P) and has the lowest total program costs. This study demonstrates that it would be possible for local authorities to raise cost efficiency through better targeting based on alternative programs for implementation. The FyrisSKZ database is available for 13 000 sub-catchments covering all of Sweden.

The Swedish buffer zone cost data base is available at <http://fyriskz.slu.se/haro/>

POSTER PRESENTATIONS



IMPACT OF CONTINUOUS APPLICATION OF PAPERMILL AND LIMING MATERIALS ON SOIL MICROBIAL COMMUNITY STRUCTURE AND BIOMASS C, N AND P

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Microbial activities in soils receiving papermill biosolids (PB) and liming materials may impact the microbial biomass carbon (MBC), nitrogen (MBN) and phosphorus (MBP). The objective of this study was to evaluate the residual effect of nine annual applications of PB and different liming materials on community structure and MBC, MBN and MBP. Treatments consisted of four PB rates (0, 30, 60, and 90 wet Mg ha⁻¹), three liming by-products (calcitic lime, lime mud, and wood ash, each at 3 wet Mg ha⁻¹ with 30 Mg PB ha⁻¹), and a mineral N fertilization (120 kg N ha⁻¹ for grain corn and 20 kg N ha⁻¹ for dry bean and soybean) surface applied annually at post-seeding to a loamy soil. Three years after treatment application, soils were sampled in each plot after harvest in the 0 to 15 and 15 to 30 cm layers. The MBC, MBN, and MBP were higher in surface (0-15 cm) than subsurface (15-30 cm) layers. The PB application rate increased significantly MBC and MBN in the surface layer only. In contrast, PB rate showed no significant effect on MBP in the 0-15 cm layer but increased MBP in the 15-30 cm layer. Application of wood ash supplemented with PB significantly increased MBP at both depths. Total phospholipid was higher in the surface than the subsurface layers. Principal component analysis showed that liming by-products supplemented with 30 Mg PB ha⁻¹ were significantly separated from PB applied alone in both soil layers. The community structure under the PB regime was more widespread along first axis for the surface layer and in the second axis for the subsurface layer. Mineral N fertilization tended to cluster with control (0 PB) in the 0-15 cm layer and with the liming by-products in the 15-30 cm layer. This study indicated that soil microorganisms immobilized C, N, and P with increasing rate of PB added, even a few years after treatment application. Moreover, the community structure was specific to treatment. Globally, application of PB alone or combined with liming materials resulted in an improvement of soil biological attributes which can be sustained for years.

REACHING THE TARGET SOIL PHOSPHORUS CONCENTRATION ZONE FOR OPTIMUM CROP YIELDS AND LIMITED P LOSSES TO WATER

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The aim of this review study was to merge the knowledge and legislation about phosphorus (P) in Europe. We wanted to generate guidelines for measures to reduce phosphorus losses from agriculture to surface waters. Phosphorus concentrations in European surface waters generally exceed ecological thresholds. The Nitrates Directive and the Water Framework Directive ask the Member States to address this problem. The resulting monitoring networks and P concentration standards differ widely among Member States. Because agriculture is considered to have a large impact on the surface water P concentrations, the diffuse P losses from soils with high P contents are targeted. Attempts have been made to reduce the soil P concentration under the threshold above which P losses increase exponentially (dashed line in Figure 1). However, agro-economical interests should also be taken into account. Farmers are reluctant to reduce P fertilisation because they fear that reduced soil P concentrations will result in reduced crop yields and quality (solid line in Figure 1). A target zone of soil P concentrations with optimum crop yields and limited P losses can be defined (grey zone in Figure 1). In order to reach or stay in this target zone, fertilisation recommendations should be adapted to include the risk for P losses. Soil P application standards are ideally differentiated to soil P concentrations. In this way, soils with large P concentrations should receive less P in order to reduce the P losses (movement from the right-hand side of Figure 1 towards the target zone) and soils with small P concentrations can receive more P to ensure satisfactory crop yields (movement from the left-hand side of Figure 1 towards the target zone).

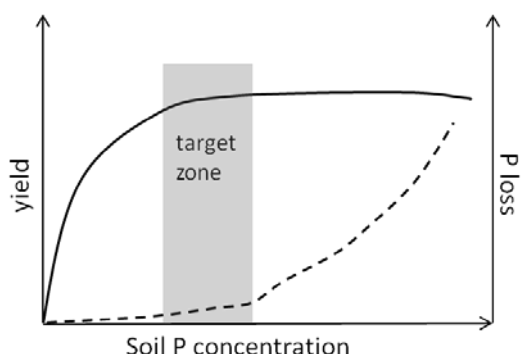


Figure 1. Crop yield (solid line) and soil P loss (dashed line) vary with increasing soil P concentration. A target zone with optimum yields and limited P losses is defined.

TOPSOIL AND SUBSOIL PROPERTIES INFLUENCE PHOSPHORUS LEACHING FROM FOUR AGRICULTURAL SOILS

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Eutrophication is largely caused by non-point source pollution by phosphorus (P) from agricultural soils. Swedish agriculture is estimated to contribute 40% of the total anthropogenic net load of P to the surrounding coastal areas. Several P leaching studies have been made on soils with well-documented chemical characteristics of the topsoil. Many researchers have stressed the importance of subsoil for P leaching but few studies have considered actual P sorption and desorption of the topsoil and subsoil separately. This study investigated the influence of soil P content, physical properties and sorption characteristics in topsoil and subsoil on P leaching measured during 21 months in 1-m long, undisturbed soil columns of two clay and two sandy soils. Total P losses during the period ranged between 0.65 and 7.40 kg ha⁻¹. Dissolved reactive P dominated in leachate from the sandy soils and one clay soil, varying from 48 to 76%, whereas particulate P dominated from the other clay soil, where low pH (5.2) in the subsoil decreased aggregate stability and thereby probably increased the dispersion of clay particles. Soils with high sorption capacity (PSI) and low P saturation (<10% of PSI) had small P leaching, despite high extractable P (Olsen P) in the topsoil, whereas a soil with low sorption capacity and high P saturation (>35% of PSI) in the profile had large P leaching. High sorption capacity in the subsoil was shown to be more important for P leaching than P content in the topsoil, especially on sandy soils. The effect of high sorption capacity on P leaching in clay soils with macropore flow in the subsoil was lower due to less contact between percolating water and the soil matrix. These results suggest that P leaching is greatly affected by subsoil properties and that topsoil studies, which dominate current research, are insufficient for assessing P leaching in many soils.

EFFECT OF ANIMAL MANURE COMPOSTS ON SOIL PHOSPHORUS CHEMISTRY AND THE CURRENT SOIL P TEST IN ONTARIO, CANADA

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Organic nutrient management, involving applications of animal manures and composts, provides both organic matter and plant available nutrients to soils. These amendments affect the chemistry of soil phosphorus (P) altering both the amount and distribution of the various P fractions. Manures and composts vary widely in their amounts and distribution of organic and inorganic P forms, which are affected by its source, the animal's physiology and diet, bedding material, and the method of storage and preparation. Therefore the nature of these P sources is not well understood. Organic farmers in Ontario report that the official soil P (Olsen) test does not provide an accurate index of plant available P in their soils. The objectives of this study are to quantify the forms of P in animal composts, and to measure the kinetics of their transformation in soils. The transformations of various P forms during an 18-week incubation were analyzed in an organically-managed calcareous soil amended with either turkey litter compost (TLC) or synthetic fertilizer. A sequential P fractionation method for calcareous soils was used to assess these transformations. Soil organic P pools were extracted using an EDTA-NaOH method and organic P was characterized by solution ³¹P NMR spectroscopy. The amounts of total P and inorganic P in each extract were measured by ICP-OES and Autoanalyzer, respectively. A soil P mineral speciation model was constructed based on their solubility reactions and constants of the major soil P minerals. The study showed that the majority of P exists in TLC was inorganic P (> 90%), and especially octacalcium phosphate (OCP) pool accounted for 69% of total TLC-P. Amendment with synthetic fertilizer affected brushite (labile P) pool most as expected, while the effect of TLC amendment was mainly on the OCP pool. The model predicts that OCP will dissolve in TLC amended soils, when soil pH is 7.0, however, the Olsen soil P test does not extract OCP, which is a precipitate at a pH of 8.5. Large amounts of OCP are added to soils with animal manures and composts, and these forms of P can supply plant available P in organically-managed soils. The Olsen soil P test was not designed for soils where organic amendments rich in OCP are the main P source. Since OCP is not extracted, this method may not adequately assess plant available P in organically-managed soils.

PHOSPHORUS SUPPLY TO THE SOIL BY A COMPOST OF POULTRY MANURE

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Phosphorus (P) is one of the essential nutrients for plants. Its availability for crops depends on the soil parent material and the organic or inorganic fertilizers applications. The poultry manure compost is an important source of organic matter (OM) and essential nutrients such as nitrogen (N) and P. The aim of this work was to evaluate the effect of a compost produced from poultry manure on the availability of P in soil and on sunflower production under greenhouse.

The study was carried out in a greenhouse where two planting beds were prepared in order to grow sunflowers. Different doses of compost were applied mixing it with the soil on the first centimeters of deeps before the sunflower plantation. Doses in the first planting bed were 1: 0 L m⁻², 2: 8 L m⁻², 3: 16 L m⁻² and 4: 30 L m⁻², whereas the doses in the second planting bed were 1: 0 L m⁻², 2: 30 L m⁻², 3: 60 L m⁻² and 4: 90 L m⁻². Inorganic fertilizers were not applied. In order to analyze P soil concentration, soil samples were taken at the plantation and the harvest and it was measured by the method of Bray and Kurtz I. The sunflower biomass production was also measured at harvest. Phosphorus soil concentration was increased when compost dose increased. In the first planting bed, in spite of the high P concentration before the compost applied (152 mg kg⁻¹), it was observed a significant difference ($\alpha > 0.01$) between the treatment without compost and the one with the lowest dose. In the same flower bed it could be observed an increment of 250 mg kg⁻¹ in P concentration with the highest dose. In the second planting bed, where the higher doses of compost were applied, it could be seen a difference of almost 400 mg kg⁻¹ of P concentration between the treatment without compost and the rest. It was no significant difference in P concentration in soil among the higher doses of compost. Finally, in regard to the sunflower growth, an increment of aboveground biomass was observed in the treatment with the higher dose. Thus it could be concluded that the application of compost increased P concentration in soil improving soil fertility.

SPATIAL VARIABILITY OF PHOSPHORUS IN DIFFERENT SOILS OF ARGENTINA REPUBLIC

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Soils properties are heterogeneous and their spatial variability depends on edaphoclimatic factors such as original material, topography and climate, as well as antrophic factors. Thus it is very important to determine soil nutrient concentrations and the specific requirements of different crops in order to carry out rational fertilisation. Among the essential nutrients, phosphorus (P) is a macronutrient that presents a high spatial variability. Spatial variations can be evaluated through geostatistical techniques that allow mapping and delineate areas of homogeneous management. This work evaluated the spatial variability in available phosphorus in four different soils of the Pampas area of Argentina, two Vertic argiudols (one located in Parana, Entre Rios and the other in San Andres de Giles, Buenos Aires), a Typic hapludol in General Villegas and a Typic argiudoll in Azul, both located in Buenos Aires. A 1-ha plot was sampled with a 25-cell grid, collecting compound samples at two depths, before sowing of soybean in two consecutive growing seasons. Phosphorus availability was measured by the Bray and Kurtz method. The availability of plant nutrients in the 0-20 cm layer was estimated on a weighted average of 0-5 and 5-20 cm. Result interpretation was based on the critical value rank cited by INTA. Descriptive statistics and geostatistic techniques were used to analyse data and to generate P distribution and availability maps through interpolation. The availability of P varied greatly between the four sites. In Paraná, extractable P content was 17.2 mg kg⁻¹ with a coefficient of variation (CV) of 41%. In San Andrés de Giles the extractable P content was 4.2 mg kg⁻¹ and CV was 34%, both considered extremely high. In General Villegas extractable P was 10.9 mg kg⁻¹ and CV 26%, and in Azul it was 9.2 mg kg⁻¹ and CV was 22%, both also considered high. Most of the variability showed moderate to strong spatial dependence, allowing the adjustment of semivariograms. The high variability of these nutrients shows the importance of agronomic practices that achieve high performance with the least environmental impact, such as site-specific precision fertilisation.

MEASUREMENT OF ^{13}C AND ^{15}N STABLE ISOTOPES TO EXAMINE THE SPATIAL FUNCTIONALITY OF RIPARIAN BUFFER STRIPS AS PART OF THE UK DEFRA DEMONSTRATION TEST CATCHMENT (DTC) PROJECT

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Riparian buffer strips can be an effective mitigation option for the reduction of sediment and nutrient transfer from agricultural land to watercourses. However, their functioning and efficiency is still relatively poorly understood, including their effectiveness over time. The timescale over which buffer efficiency varies will depend on many factors including land use, topography, soil type and buffer management. This study examined the variations in the natural abundance of carbon (C) and nitrogen (N) stable isotopes to provide an indication of the spatial functional variability of buffer strips of different ages. In addition, these data were compared with variations in phosphorus (P) forms found within the buffer strips. Four established riparian buffer strips in the north of the Hampshire Avon Demonstration Test Catchment (DTC) were sampled during summer 2010. The 6 m buffer strips ranged in age from 4 – 10 years old and all were sited on well drained loamy glauconitic soil overlying greensand. Five sampling transects were established at each site, one in the upslope arable field and four within the buffer strip at 0m, 2m, 4m and 6m from the field/buffer interface. Soil samples were collected at three depths; 0-7 cm, 7-23 cm, and 23-30 cm along each transect, and analysed for total N, C and P, ^{15}N , ^{13}C , water soluble P and pH.

No relationship was found between buffer age and the distribution of ^{15}N and ^{13}C in the buffer strips suggesting that factors other than age (e.g. buffer management) may have greater importance in determining the performance of buffer strips. In two buffer strips, ^{13}C enrichment was observed, with concentrations increasing across the buffers towards the water body boundary. Further investigations have shown this can be attributed to the presence of carbonate in those buffers. Water soluble P concentrations were considerably lower in the buffers having ^{13}C (carbonate) enrichment. This may be due to increased adsorption of labile P to calcium carbonate, and could have implications for increasing the efficacy and longevity of buffer strips as a mitigation option for the reduction of P transfer to water courses.

PHOSPHORUS LOSSES FROM CATCHMENTS WITH LOW AND HIGH AGRICULTURAL INTENSITY - RAINFALL SIMULATION PLOT STUDIE

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The Smrzovsky catchment (3.6 km²) is situated in a landscape protected area and the farmers are not allowed to use mineral fertilisers. The soils are podzol and cryptosol. Grazing of cattle in this area went on in August, i.e. about 2 months before the experiment. At the beginning of experiment there were remains of dung on the pasture. The cooperative on the Kralovsky catchment (3.2 km²) grows crops such as rape, wheat and corn. The soil type is acid brown soil with insufficient sorption complex. On the ploughed sloping down field fertilisation with manure (350 kg ha⁻¹) was done two weeks before the start of the experiment.

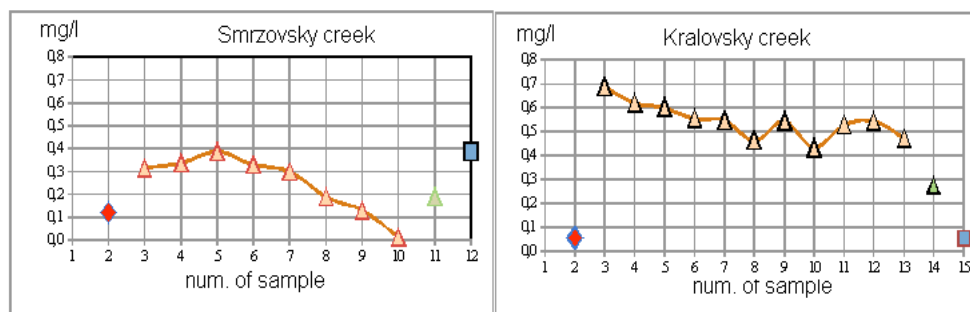


Figure 1. Concentrations of dissolved phosphorus during experiments with simulated rain of high intensity; black diamond – source of water (water truck filled in the upper part of the Smrzovsky creek and water from a nearby tributary on Kralovsky creek), grey triangle - composite final sample from the collecting vessel, grey square - stream water collected at water gauge site.

The experiment itself consisted in manual watering an experimental area (5 m long 1m wide). Rain intensity was 80 mm hr⁻¹ on Smrzovsky creek and 92 mm hr⁻¹ on Kralovsky creek. Water from the surface and near subsurface was captured in a vessel below the terrain level and sampled before passing into the collecting vessel and analyzed for P dissolved, P-PO₄⁻, P total, N-NH₄⁺, N-NO₃⁻ and K⁺. Results of the analysis of soil samples before and after the experiment show that P (Olsen) remained practically the same on the Smrzovsky creek 23 mg kg⁻¹, but changed from 44 to 60 mg kg⁻¹ of dry matter of soil on the Kralovsky creek. The experiments with artificial rainfall document well the difference in phosphorus loss between pasture and growing crops.

DEVELOPING RELATIONSHIPS BETWEEN STREAM WATER PHOSPHORUS AND ECOLOGICAL ENDPOINTS IN OZARK HEADWATER STREAMS

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Phosphorus (P) is a key limiting nutrient of freshwater eutrophication, a major impairment to designated uses in the U.S. Efforts have focused on reducing nutrient and sediment losses from agricultural lands with the objective of improving water quality. While measures are available to reduce edge-of-field losses, water quality improvements at a larger, watershed scale have not always occurred.

Stream water numeric criteria developed for Illinois River Watershed (IRW) of 0.037 mg total P L⁻¹, was based on the frequency distribution of flow-weighted P in undeveloped rivers. However, a recent independent review stated that the US EPA stressor-response approach is the most appropriate, scientifically based method for developing numeric nutrient criteria, as long as it is used in conjunction with a 'weight-of-evidence' approach. Thus, it is essential that algal-response characteristics be determined as a function of in-stream P sources and processing to provide the needed 'weight-of-evidence' data for IRW streams. The objectives of this study were to examine the relationship fluvial P sources and algal biomass accumulation.

A mesocosm experiment was conducted which simulated the release of P during baseflow from sediment deposited in a stream. Periphyton biomass (as chlorophyll-a) was determined after 8 days after tiles inoculated in IRW stream were equilibrated with soils of varying P levels in 700 mL water. As expected, there was a positive linear relationship between the Mehlich-3 P content of stream sediment and stream P ($R^2=0.99$) as well as biofilm chlorophyll-a ($R^2=0.75$). Future work will examine these relationships in flume experiments.

PHOSPHORUS BALANCES AND USE EFFICIENCIES ACROSS GRASS BASED DAIRY PRODUCTION SYSTEM IN THE REPUBLIC OF IRELAND

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There is an increasing interest in the environmental performance and efficiency of different farming systems and policymakers are seeking reliable indicators of sustainability. Farm-gate nutrient balances and nutrient use efficiencies are such indicators and have been proposed as a means of assessing nutrient management efficiency at farm level while providing an indicator of environmental pressure. This study estimates farm gate P balances and use efficiencies for a cohort of specialist Republic of Ireland dairy farmers (n=195) on grass based systems using EU Farm Accountancy Data network data over 2 years (2009 & 2010).

Results indicate the total average farm gate P balance was 4.1 kg ha⁻¹ in surplus. P balance ranged from -7.3 to 23.0 kg ha⁻¹. Average farm-gate P use efficiency in this study was found to be nearly 84%. Total farm gate P imports averaged 13 kg ha⁻¹, ranging from 2.0 – 33.1 kg ha⁻¹. In total, 52% of farm gate P imports were derived from chemical fertiliser (6.7 kg ha⁻¹) and 42% from concentrate feed (5.5 kg ha⁻¹). Milk was the main source of P export from farms, averaging 63% of total P exports (5.6 kg ha⁻¹). Livestock was the other main output, accounting for 35% of total P exports (3.1 kg ha⁻¹).

Results indicate a cohort of dairy farmers are mining soil stores of P as 27% of the sample had a negative P balance. Dairy farmers in the Republic of Ireland are permitted to farm at a stocking rate of between 170 and 250 kg (20% of this sample) organic N ha⁻¹ subject to a derogation under Ireland's EU Nitrates regulations and are required to submit an annual nutrient management plan underpinned by a soil test to secure this derogation. They face restrictions on P importation under this derogation. Interestingly, the average P surplus for farms with this derogation was below the average of all farms at 3.5 kg P ha⁻¹, suggesting these farms are more tightly managing P resources.

Findings from this study suggest that specialist dairy production from grass based system across the Republic of Ireland have one of the lowest P surplus and highest P use efficiencies reported internationally.

SUBMERGED FILTERS FOR PHOSPHOROUS REMOVAL FROM SMALL WATER BODIES

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Pollutants in runoff from rural areas, mainly from non-point sources, influence the environment of water bodies. Of particular importance is phosphorus as high water concentrations usually cause eutrophication.

The aim of this study was to assess the efficiency in P-PO₄ reduction by the reactive material Polonite® as a submerged filter. This was placed in a stream situated in an agricultural catchment characterized by podsolic soils. The stream is flowing through Sokolow Podlaski town, Poland. Polonite® is a silica-calcite sedimentary rock (opoka) heated at a temperature of 900°C. The P-sorption active fraction of Polonite® is calcite, which contains 40% of the material. The experiment was conducted with different ratios reactive material to water volume and with natural surface water, pre-filtered surface water and artificial P solution.

During 30 days of experiments 1 g of Polonite® removed from 0.07 to 0.3 mg P-PO₄ L⁻¹ at different mass to volume ratios. This corresponded to a reduction from 38% for pre-filtered surface water (1:1 mass to volume ratio) to 90% for artificial P unfiltered solution (10:1 mass to volume ratio). There was no significant relationship between initial P-PO₄ concentration and total load of P removed and the correlations found were weak: for surface water, filtered surface water and for artificial P solution R²=0.27, R²=0.28 and R²=0.16 respectively. The pH at the beginning of each experiment equaled 6.3-7.8 and after 30 days it reached 8.3-10.9. There was a good correlation between observed maximum pH value and mass of Polonite used to each experiments: 0.90, 0.97 and 0.78 for artificial P solution, natural surface water and pre-filtered surface water, respectively.

Tested reactive material may be used as a supplementary method of surface water treatment of phosphorus together with other eco-technology methods like constructed wetland systems. Submerged filters may reduce the concentration of P-PO₄ in water from small water bodies like agriculture reservoirs, streams, watercourses or drainage ditches if the retention time is at least 24 hours.

MICRO-VARIABILITY OF SOIL P DISTRIBUTION IN A LONG TERM EXPERIMENTAL SITE FROM EASTERN CANADA: COMPARISON BETWEEN NO-TILL AND MOULDBOARD PLOUGH PLOTS

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The P banding in no-till (NT) management systems increase the horizontal and vertical soil P spatial distribution. The objectives of this study were to (i) characterise micro-spatial variability of soil P in NT and mouldboard (MP) plots using 2D geostatistical analyses, (ii) describe the pattern of soil P distribution about the seeding row, and (iii) determine the appropriate soil sampling area and depth under NT and MP systems. The site was established in 1992 on a clay loam soil under a maize-soybean rotation with 2 tillage practices and 3 annual band-applied P rates as triple super phosphate (0, 17.5, 35 kg P ha⁻¹) at maize planting. Six experimental units (MP and NT, 35 kg P ha⁻¹ yr⁻¹, 3 blocks) were sampled with a nested grid sampling method. The main grid (2.5 m x 0.38 m distance between each 35 sampling points) consisted of 7 transects (perpendicular to row direction) and five transects (located on 3 interrows and 2 maize rows i.e. 3rd and 4th rows plot). Three of the 7 transects had more intensive interrow sampling points (0.076-m between the sampling point perpendicular to the row; 16 additional sampling points per transect). A total of 996 soil samples (=83 per depth x 2 depths x 6 experimental units) were collected. On average, Mehlich-3 P (P_{M3}) was higher in NT than MP at both depths (0-5 cm: 3.1 vs 1.9 mg P kg⁻¹; 5-20 cm: 1.8 vs 1.5 mg P kg⁻¹).

Under MP, P_{M3} varied between 0.4-13 and 0.3-10 mg P kg⁻¹ in the 0-5 and 5-20 cm layers, respectively. Under NT, P_{M3} varied between 0.5-11 and 0.3-8.4 mg P kg⁻¹ in the 0-5 and 5-20 cm layers, respectively. Only, 1 of 3 MP plots showed spatial dependence at both depths. Two of three NT plots showed spatial dependence in the 0-5 cm layer. The R² of the cross-validation were < 0.17. In general, the semivariogram parameters revealed weak spatial structure indicating a predominance of random factors in P_{M3} distribution. ANOVA revealed a significant difference between depths whatever soil treatments or positions. We concluded that similar sampling strategy design would be suitable for both tillage systems in this long term maize-soybean rotation.

SEASONAL VARIATION IN PHOSPHORUS EXPORT FROM AGRICULTURALLY-DOMINATED WATERSHEDS IN THE NORTHERN GREAT PLAINS, CANADA

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Nonpoint nutrient sources are difficult to quantify and manage because they come from activities dispersed over wide areas and are variable in time due to the role of weather and climate in determining the frequency and intensity of runoff. In regions that experience annual weather extremes (e.g., central regions of North America and northern regions of Asia), non-point inputs should mirror the seasonal hydrologic pattern of high discharge during spring snowmelt, smaller discharge with occasional rainfall-induced spikes during summer and fall, and low or no discharge during winter when channels are frozen all or in part. Our aim was to determine changes in phosphorus export across hydrologic seasons and along rivers in the northern Great Plains of Canada, as part of a larger project to quantify nutrient export to a large hyper-eutrophic lake, Lake Winnipeg. Longitudinal gradients were established along three tributaries to the Red River, Manitoba, Canada by selection of sampling sites located upstream, mid-stream and downstream on each tributary. Discharge and total phosphorus (TP) data were obtained from government sources or collected by the authors. Each year was divided into four hydrologic seasons: snowmelt characterized by high discharge (March to April), summer associated with rain events (May to August), fall characterized by low flow (September to October), and winter featuring an ice-cover period with low flow and/or a completely frozen channel (November to February).

Annual patterns in discharge and loading in all rivers were strongly influenced by the snowmelt period: 26-89% of the total annual river volume and 29-92% of the annual TP load were delivered during snowmelt. Concentrations of TP varied among hydrologic seasons but showed more variability and larger values during winter and snowmelt, reaching 1.96 mg L⁻¹. Our results showed that TP export from northern Great Plains rivers were strongly influenced by seasonal hydrology, with snowmelt being a critical period for nutrient export. The flat topography and semi-arid to sub-humid continental climate of the northern Great Plains results in unique patterns in annual discharge and nutrient export, which has implications for design and implementation of appropriate management practices to minimize nutrient export to proximal and downstream aquatic ecosystems.

IMMOBILIZING SOIL PHOSPHORUS FOR NATURE DEVELOPMENT

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A high soil content of plant available P is an indication of a risk for P leaching to surface water. However, it is also a bad starting point for nature development on former agricultural soils. Decreasing plant availability of P can thus both decrease P leaching risk and improve the chance for developing a species rich vegetation.

In a lab experiment we tested two side products of drinking water production for decreasing P availability in soil samples. The first product originates from aerating anaerobic groundwater that contained dissolved iron as Fe^{2+} . This causes Fe to precipitate as iron(hydr)oxides, that is removed from the water via a sand bed and a sedimentation basin, and has a dry matter content of ca 10-20 %. The second product is formed after adding poly aluminium chloride to surface water, in order to remove suspended matter for drinking water production. The aluminum(hydr)oxides are then removed in a sedimentation basin, giving a sludge with a much lower d.m. content of about 2 %.

The required amount of sludge was calculated by setting a target value for the P Saturation Index: the ratio of oxalate extractable P/(Fe+Al); a target of PSI=0.1 was chosen. The PSI is a good predictor of water extractable P (Pw), the Dutch parameter used for agricultural available soil P (Chardon, 1994). It was aimed to mix either Fe- or Al-sludge with field moist soil samples, and to incubate the mixture at 60 % of the soil Water Holding Capacity. However, for Al-sludge this was not possible due to the very low d.m. content of 2 %, so a mixture was made of soil and sludge at 1:1 ratio (v:v).

During incubation with Fe-sludge the soil was tested on P- CaCl_2 , Pw and P-Olsen. Both P- CaCl_2 and Pw decreased within 3 days: P- CaCl_2 90% and Pw 70%, to values classified as P availability low - very low. However, values of P-Olsen remained much higher, with soil P status optimal - high. This makes it doubtful if P-Olsen is a good parameter for judging soil P status after immobilization.

Although only a few preliminary measurements were made after using Al-sludge, Pw seemed to decrease even faster than with Fe-sludge. Maybe the large amount of water added with the Al-sludge caused better mixing than the drier Fe-sludge.

Chardon, W.J. 1994. Relationship between phosphorus availability and phosphorus saturation index. Report 19, Inst. for Agrobiol. and Soil Fert. Res., Haren.

LINKING THE BENTHIC CYCLING OF P TO ITS SURFACE WATER DYNAMICS IN LAKES

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Sediment plays a key role in phosphorus (P) biogeochemical cycling in aquatic environments, sequestering and burying P that settles out from the water column. When external inputs lead to significant storage of P in the sediment, P remobilisation to the water column may delay the recovery of the lakes after inputs to the water column have peaked. This complex response of sediment P cycling to changes in the water and sediment conditions, which depends on the specific forms of sediment-bound P, can be predicted over long time scales using diagenetic models. Here, we implemented diagenetic processes at the sediment-water interface (SWI) in an existing dynamic catchment-scale model for P and quantified the timing and magnitude of P exchanges between the water column and the sediment.

First, an existing model chain, comprising a hydrological water-balance model (HBV), a watershed-scale model (INCA-P) and a water-column model (MyLake), was calibrated using a 11-year dataset of total-P, phosphate-P (PO₄-P) and particulate organic-P (P_{org}, = Total-P minus PO₄) in the water columns of two eutrophic lake basins in the Vansjø-Hobøl watershed in Southern Norway. A process-based sediment diagenesis module (MATSEDLAB) was then incorporated within the lake model. The code includes a representation of the effect of benthic macrofauna on P cycling, allows non-steady state boundary conditions and includes diagenetic processes representing the microbial degradation of organic matter (OM), secondary redox reactions, sorption and mineral precipitation.

The model confirmed that the mineralisation of OM and associated P_{org} at the SWI drives the production of mobile PO₄, which can then diffuse from the sediment to the water column. Benthic PO₄ efflux is closely correlated to the thickness of the surficial Fe (oxy)hydroxide layer, to which P is sorbed. The model also showed that anoxia (caused by high OM fluxes to the SWI) and sulphide production (enhanced by historical variations in sulphate inputs to the lake following acid rain deposition) triggers reductive dissolution of Fe (oxy)hydroxides and reduces the capacity of sediment to sequester P. Throughout the simulation, however, the sediment remained a net sink for P and should continue to do so provided that the bottom water oxygen concentration remains high enough to ensure the stability of the Fe (oxy)hydroxide layer.

EXTRACTION WITH 0.01 M CaCl_2 GENERALLY RESULTS IN UNDERESTIMATION OF SOIL SOLUTION P CONCENTRATION

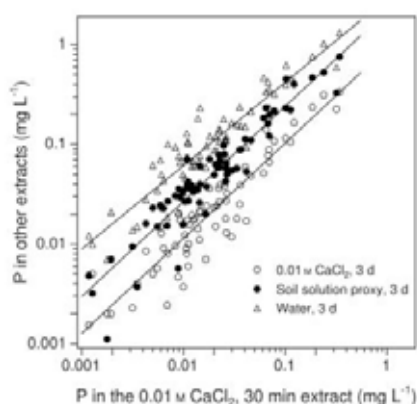
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Water and 0.01 M CaCl_2 are the extractants commonly used in tests measuring the intensity factor of soil P. The latter has been used for more than 50 years on the basis of its similitude to the solution of most agricultural soils. Although water and 0.01 M CaCl_2 extractable P have been found to be correlated, the concentration of P in the water extract is generally several times greater than that in the 0.01 M CaCl_2 extract. This discrepancy can be partly ascribed to the different ionic strength and composition of the two extracting solutions. In this work, we measured the P extracted by a salt solution similar in ionic composition and strength to the soil solution. Our purpose was to find out to which extent the extractions with water and 0.01 M CaCl_2 offer a view of the actual concentration of P in the soil solution. Seventy Spanish soils were used, extraction being performed for 3 days at 25 °C using a soil:solution ratio of 1:10. A 30-min extraction with 0.01 M CaCl_2 was used as the reference method.

Extraction time had little influence on 0.01 M CaCl_2 extractable P. On average, water extractable P was about 2.3 times the soil solution proxy extractable P, and 0.01 M CaCl_2 extractable P was about 0.4 times the soil solution proxy extractable P. The figure below offers details of the extraction data.



The ratio between 0.01 M CaCl_2 extractable P and soil solution proxy extractable P approached 1 as the ionic strength of the soil solution approached that of 0.01 M CaCl_2 . This suggests that a better estimate of the concentration of P in the soil solution is obtained if a CaCl_2 extracting solution with ionic strength similar to that of the soil solution is used.

FACTORS AFFECTING THE PREDICTIVE ABILITY OF THE OLSEN TEST IN REPRESENTATIVE MEDITERRANEAN SOILS

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A sound management of soil P requires that soil P tests have a good predictive ability. In particular, the Olsen test is widely used for soils in the Mediterranean climate regions but little is known on soil factors controlling the relationship between P bound to soil particles and P in solution and its uptake by the plant. This work was aimed to assess which soil properties affect the relationship between Olsen P and P uptake by plants in representative Mediterranean soils. To this purpose, pairs of samples from the same soil but differing markedly in Olsen P level (“high-P” and “low-P” samples) were taken in 17 localities. A P starvation experiment using cucumber was done in duplicate using

350 mL pots containing a mixture of sand and an amount of soil equivalent to 1 mg of Olsen P. For each soil, a sequential inorganic P fractionation was performed involving NaOH- and citrate/bicarbonate (CB)-extractable P, which provide an estimate of the more labile P forms. The Fe bound to Fe oxides was determined as the sum of Fe successively extracted by citrate/ascorbate and citrate/bicarbonate/dithionite. The amount of P taken up by cucumber and the phosphatase activity in the rhizospheric soil after cropping were measured.

Olsen P in high-P samples ranged from 9 to 49 (mean = 24) mg kg⁻¹, and low-P samples ranged from 4 to 16 (mean = 9) mg kg⁻¹. Plant P uptake ranged from 0.07 to 2.3 (mean = 0.67) mg pot⁻¹ in high-P samples and from 0.03 to 1.2 (mean = 0.5) mg pot⁻¹ in low-P samples. Therefore, Olsen P did not accurately predict plant P uptake. Phosphorus uptake in high-P samples was only correlated to the Fe content ($R^2 = 0.56$, $P < 0.001$). In low-P samples, P uptake was correlated to the amount of inorganic NaOH-P+CB-P ($R^2 = 0.69$, $P < 0.001$), and to phytase hydrolysable P in CB extracts ($R^2 = 0.36$, $P < 0.05$) in the pot. Alkaline phosphatase activity in rhizosphere and organic P in the pot explained 37% of the variation in P uptake in low P soils ($P < 0.05$). These results show that, in high-P samples, properties related to the Fe oxides, such as buffer capacity, affect the accuracy of Olsen P as a phytoavailability index. In low-P samples, the mobilization of some inorganic P from the NaOH-P + CB-P fraction, the phosphatase activity, organic P, and some phytase hydrolysable fractions contribute to phytoavailable P.

EFFECT OF THE BICONTROL AGENT *TRICHODERMA ASPERELLUM* T34 ON THE P UPTAKE BY PLANTS FROM DIFFERENT SOURCES

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To overcome the consequences of phosphate rock depletion and increasing prices of P fertilizers, an enhanced efficiency in the use of fertilizer and soil P by plants is necessary. P solubilising microorganisms can contribute to the uptake of P by plants. For a sustainable agricultural management, additional benefits from these microorganisms will be desirable. The objective of this work was to study the contribution of the biocontrol fungus *Trichoderma asperellum* T34 to the use of different P sources by cucumber in order to study its potential use for an integrated management of plant diseases and nutrition. To this end, a completely randomized experiment was performed twice involving two factors: (i) inoculation/no inoculation with T34, and (ii) P source (phosphate, phytate, and phosphate rock). Plants were grown on siliceous sand and Fe oxide adsorbed on the sand as Fe source. The same dose of P was applied (6.4 mg P kg^{-1}) for each source; phosphate and phytate was applied adsorbed on Fe oxide (200 mg of citrate-ascorbate extractable Fe kg^{-1}).

Phosphorus uptake by cucumber was not different with phosphate and phytate, thus revealing the plant ability of using phytate as P source. The exudation of oxalic acid by plants was twice with phosphate rock than with other sources. T34 increased dry matter yield, total P in roots (by 30 %), and total Fe in shoots and roots. The effect of T34 on total P in shoots and the total P uptake by plants depended on the P source: T34 increased both variables (by 30 %) when P was supplied as phytate and rock phosphate. This effect could be related to an increased alkaline phosphatase and phytase activity. T34 promoted a slight (0.1 unit) but significant decrease of pH in the rhizosphere which can be related to P mobilizing strategies. T34 decreased oxalic acid in the rhizosphere with phytate and phosphate, but not with phosphate rock, which perhaps reveal a production by T34 to increase the solubilisation of P. Overall, phosphatase and organic acids in the rhizosphere explained 31 % of P uptake ($P < 0.001$). Total P uptake was related to Fe uptake, perhaps evidencing a link between Fe acquisition strategies and P availability. However, P uptake by plants was less dependent on Fe accumulation with T34, which probably reveals an increased P mobilisation capacity with T34 in the medium.

EFFECT OF DIFFERENT MICROORGANISMS ON THE UPTAKE OF PHOSPHORUS BY PLANTS FROM INSOLUBLE CALCIUM PHOSPHATES

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Phosphorus solubilising bacteria has been studied as a tool to increase the availability of this nutrient to plants. Additional benefits with the inoculation with these organisms will be desirable to achieve economical sustainability of agricultural practices. The objective of this work was to study the contribution of the biocontrol agent *Trichoderma asperellum* T34 and two growth promoting bacteria (*Bacillus amololiquescens* and *B. subtilis*) to the uptake of P from ground phosphate rock by plants. Two experiments were performed: (i) the first with cultivation of microorganisms in liquid media to study mechanisms involved in P release, and (ii) the second involving plant inoculation in calcareous growing media. In both experiments, two factors were considered: (i) P source (inorganic phosphate–Pi– and ground phosphate rock –PR–), and (ii) microorganism (four treatments, the three mentioned and one control without inoculation). P concentration in liquid culture was 1 g L⁻¹, and P rate in the plant experiment was 200 mg kg⁻¹.

In the liquid culture, oxalic acid was produced by the three organisms and its production depended on the P source (significant interaction between factors); *B. subtilis* produced the highest amounts of oxalic acid with PR, meanwhile *B. amololiquescens* and T34 produced more oxalic with Pi. Citric was detected in bacillus cultures. pH in the liquid media was unaffected with Pi, and was decreased from 7.5 to 4.1 by both bacillus with PR, thus revealing its acidification capacity when P was applied as PR. There were not differences in phosphatase activity produced by the 3 microorganisms with Pi; with PR, bacillus produced much more phosphatases than T34. In the plant experiment, only plants inoculated with *B. subtilis* showed greater uptake of P (by 54 %) than those non-inoculated. This can be explained by the acidification capacity and organic acid production of this microorganism as observed in the cultivation in liquid media.

INORGANIC AND ORGANIC FRACTIONS IN REPRESENTATIVE MEDITERRANEAN SOILS

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The aim of this study was to study organic and inorganic P fractions in representative Mediterranean soils. Pairs of samples from the same soil but differing markedly in Olsen P level (“high-P” and “low-P” samples) were taken in 17 localities. A sequential chemical fractionation was done, involving: NaOH, citrate-bicarbonate (CB), citrate (C), citrate-ascorbate (CA), citrate-bicarbonate- dithionite (CBD), acetate (OAc), HCl, NaOH (90 °C), and persulfate in acid media (Per). In all the fractions, molybdate reactive P and total P were determined, organic P (OP) being estimated as the difference between them, except in hot NaOH (only TP), and Per (only MRP); this latter two fractions being ascribed to OP. Total P in the soil was estimated as the sum of TP in all fractions (and MRP in Per), total inorganic P (Pi) as the sum of MRP in all the fractions except Per, and total OP as the sum of OP in all the fractions and TP in hot NaOH and MRP in Per. In all the fractions, except Per, an enzymatic hydrolysis of OP was performed using phytase.

Total OP accounted for 25 to 70 % of TP in all the soil samples, decreasing with increasing TP in soil ($R^2 = 0.43$, $P < 0.001$). In high-P samples, OP accounted for 47 % of TP, less than in low-P samples (54 % of TP). The dominant Pi fraction in soils was that ascribed to pedogenic hydroxiapatite (C), which amounted for 28 % of total Pi. This fraction was unaffected by the P status of soil and, as Pi occluded in poorly crystalline (CA-P) and crystalline (CBD-P) Fe oxides, its ratio to total Pi only depended on the soil type. This reveals that the relative relevance of these Pi fractions is more determined by geochemistry in each soil than by the P rates applied to soil. The NaOH-Pi+CB- Pi to total Pi ratio was greater in high-P samples (0.14), than in low-P samples (0.08), thus indicating that the more easily releasable P forms accounted for a greater portion of Pi in high-P samples. OP hydrolyzed by phytases accounted for 12 % of total OP in soil, being unaffected by P status in soil. The portion of total OP hydrolyzed by phytases was increased with total OP in soil ($R^2 = 0.48$, $P < 0.001$), but was not affected by soil or by P status of soil. The portion of phytase hydrolyzable OP which was extracted by HCl varied between soils, revealing that depend on soil conditions enhancing the precipitation of Ca phytates.

ACHIEVING ENVIRONMENTAL AND AGRONOMIC SOIL P TARGETS UNDER A ZERO P APPLICATION REGIME

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Despite the implementation of EU regulations controlling the use of fertilisers in agriculture, high soil phosphorus (P) concentrations remain a significant threat to water quality in Europe. This is partly due to the significant time lag between the implementation of measures and the decline in soil P to agronomic optimum levels. In order to reduce soil P sustainably, there is a need to elucidate the relationship between zero P application and soil P availability for plant growth and loss to water. Between 2000 and 2005 0, 10, 20, 40, 80 kg P ha⁻¹ was applied to five grazed grassland plots, building the Olsen soil P up to 19, 24, 28, 38 and 67 mg P L⁻¹, respectively. From 2005 to 2010, the plots received zero P applications, except for dung deposited by grazing animals. Changes in Olsen P were monitored weekly during this period. Selected soil samples from 2000, 2005 and 2010 were analysed for P forms using solution ³¹P NMR spectroscopy and P fraction using sequential extraction techniques. The results demonstrated that the decline in soil P was linearly related to the Olsen P concentration in 2005 (R² 0.99), taking up to 13 years for the soil at 67 mg Olsen P L⁻¹ to decline to the agronomic optimum. In 2005, inorganic P dominated total soil P (53-63%) in all the plots, except for the plot with the lowest Olsen P concentration (49%). By 2010 this trend had been reversed with inorganic P accounting for only 38-42% of total P in all plots except for the plot with the highest Olsen P concentration in 2005 (52%). The sequential P extraction demonstrated that the extractability of P varied significantly under a zero P fertiliser regime, the biggest impact being on P associated with NH₄Cl and NH₄F extractions, both of which are the most available to plants and for loss to water. Herbage analysis in 2010 demonstrated that, despite the decline in plant available P pools, all plots had a herbage P concentration above 3.0 g kg⁻¹, sufficient for beef cattle grazing. However, all except the plot with the highest Olsen P concentration in 2005 were below the herbage P content of 3.6 g P kg⁻¹ required for high yielding dairy cows. This study demonstrates the challenges in balancing agronomic and environmental soil P targets, particularly in intensive dairy systems where a high proportion of soils are above the agronomic optimum.

PHOSPHORUS FERTILIZING EFFECTS OF BIOGAS DIGESTATES

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For an efficient re-use of biogas digestates as fertilizers their effects on soil fertility and plant nutrition need to be evaluated. Focusing on phosphorus (P) different experiments were carried out aiming at three main objectives I) to estimate P fractions in biogas digestates from 25 different biogas plants before and after mechanical separation, II) to evaluate the effects of digestates on plant nutrition and soil P cycles in comparison to undigested slurries under semi controlled conditions III) to assess the agronomic effectiveness of digestates in a three-year field experiment. Beside the growth and P uptake of maize and amaranth organic and inorganic P fractions in the digestates and soil as well as microbial P and activities of enzymes were investigated. Usually, about 80 % of total P in the digestates was bio-available P (P_{water} , PNaHCO_3). However, lower values of bio-available P (about 35 %) were found for digestates based on food residues, where the highest amount of P was found to be soluble in H_2SO_4 . After liquid-solid separation of the digestates the solid phase contained high total P contents (up to 5.41 g kg^{-1}). The effects of the digestates on plant P uptake and soil P pools were comparable to that of undigested slurries. On the contrary, digested and undigested slurries considerably differed in their effects on soil microbiological parameters. In all experiments, microbial activity (measured as activity of dehydrogenase, DH) and alkaline phosphatase was up to 50 % lower after application of the digestates than after application of the undigested slurry (table 1). The results indicate a good P effect of biogas digestates. However, the organic matter applied with biogas residues does not stimulate soil microorganisms, which may also have consequences for microbial P turnover in soil.

Table 1. Activity of dehydrogenase (DH), alkaline and acid phosphatase (AIP and AcP) in the soil after 3 years of continuous field application of undigested slurry and digestate (means of 5 sampling dates)

Treatment	DH $\mu\text{g TPF g}^{-1} \text{ h}^{-1}$	AIP	AcP $\mu\text{g p-NP g}^{-1} \text{ h}^{-1}$
Undigested dairyslurry	26.5 b	224 c	43.5 b
Digestate	13.2 a	193 a	23.0 a
Mineral NK	12.9 a	210 b	23.6 a

TPF -triphenylformazan, NP – nitrophenol, Mean values followed by different letters in the columns indicate significant differences between the treatments ($p < 0.05$, Duncan test)

MINERALOGY AND PHOSPHORUS SPECIATION IN SOME SWEDISH AGRICULTURAL SOILS

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Several different factors determine the forms of phosphorus (P) found in soils, as well as the binding of P added to the soil. One of these factors is soil mineral composition. This work investigated mineralogy and P speciation in Swedish agricultural soils.

The mineralogy of clay and bulk soil was analysed in samples from 10 different sites in southern and central Sweden representing different soil types. Most of these sites have hosted P leaching studies. Large similarities in mineralogy were found for most of the sites, but with some exceptions. One of the sites in central Sweden (Fors) showed a high content of calcite, whereas two of the southernmost sites (Ekebo and Fjärdingslöv) had a higher content of kaolin and smectite, respectively.

One specific group of clay minerals that is reported to play an important role in the sorption of P is hydroxy-aluminium-interlayered vermiculite (HIV). Hydroxy-interlayered minerals were detected here using X-ray diffraction. More precisely, an 'interlayering index', based on the centre of gravity of diffracted intensity in the range 14-10 Å, was analysed in diffractograms collected from clay samples during heating to different temperatures. The change between 300 and 500°C was interpreted as a measure of dehydration of interlayered material, which results in a decrease in basal spacing from 14 Å to 10 Å. HIV was present in three of the samples analysed, with different degrees of interlayering. The results indicate that our interlayering index can be a useful tool to rank soils according to their content of hydroxy-interlayered clay minerals.

Using X-ray near edge adsorption spectroscopy (XANES), the speciation of P was investigated in clay fractions from six sites included in the Swedish long-term fertility experiments. Two samples were taken from treatments at each site differing in P fertiliser application rate, i.e. control (zero P application) and replacement of crop off-take plus 30 kg P ha⁻¹ yr⁻¹.

The results indicated that calcium phosphates were an important P phase in the control plots from sites with pH higher than 6. The additional P present in fertilised plots showed different ways of binding at the different sites. At most sites, sorption onto aluminium and iron oxides seemed to be important. At a site with calcareous soil (Fors), however, the added P was predominantly bound as calcium phosphates.

IMPACTS OF SOIL MANAGEMENT - WHERE IS THE PHOSPHORUS?

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The abundance and vertical distribution of phosphorus in the soil profile are affected by tillage type and tillage intensity. We therefore investigated the effects of four tillage systems on the stratification and storage of organic carbon in a 36- years old field experiment. The experiment is sited in Uppsala (Sweden) on a clay soil. The treatments investigated are: continuous mouldboard ploughing (MP); shallow tillage (ST); shallow tillage with occasional mouldboard ploughing (OP); and chisel ploughing (CP). In the treatment with occasional or periodical ploughing (OP), mouldboard ploughing was implemented once in about four years and other years shallow tillage was applied. Soil samples were taken in four layers (0-5 cm; 5-12 cm, 12-25 cm and 25-50 cm) in the treatments with reduced tillage (ST, OP and CP) and in three layers (0-5 cm; 5-12cm, 12-25 cm, 25-50 cm) in the treatment with continuous mouldboard ploughing. Phosphorus stratification followed tillage depth with very low P in the lower part (12-25 cm) of ST (Table.1). Total phosphorus stock (not shown here) in the 0-50 cm profile was greatest in OP and least in ST. Similar trend for extractable P was observed but its near soil surface accumulation was relatively high in ST.

Table 1. Phosphorus (P) concentration (mg 100 g⁻¹) in the soil profile

Depth (cm)	Total P				Extractable P			
	MP	OP	ST	CP	MP	OP	ST	CP
0-5	60.6	70.0	64.6	74.8	4.4	4.8	5.6	4.8
5-12	58.0	66.8	59.8	63.7	4.1	4.2	4.2	3.1
12-25	58.0	66.8	44.9	53.0	4.1	4.2	2.0	1.9
25-50	31.6	38.6	24.6	36.5	1.1	1.4	1.8	1.4

SIMPLE APPROACH FOR DIRECT MEASUREMENT OF PHOSPHORUS SETTLING VELOCITY

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We present a novel approach for effective evaluation of the impact of suspended solids on eutrophication of individual lake or reservoirs. Suspended particles can originate from very different kinds of sources in the watershed or river network, e.g. from freshly eroded soil particles emitted from field to stream during peak discharge caused by summer storms or snowmelt; from stream biofilm detached continuously during senescence or unexpectedly destroyed by changes in hydrodynamic conditions; from river bottom sediment resuspended by sudden floods; or from fish-pond sediment resuspended by regular annual harvest.

Through a classical pipette sedimentation method (Andreasen & Lundberg, 1930), together with subsequent chemical analyses of subsamples for total phosphorus (P) (via ICP-OES), we directly measured P settling velocity (v_P) of particles sampled in a river profile. From the time sequence of P concentration decrease obtained, we derived P sedimentation half-time (K_{Ps}) and maximum P elimination (v_{Pmax}). These allow the contribution to the final eutrophication impact of all sorts of particles entering any stagnant water body to be distinguished and their role inferred.

In a pilot laboratory study, we compared three bottom sediments from exclusively agricultural headwaters, one fish-pond sediment and one typical erosion runoff sample. For future comparability, Reference Stream Sediment STSD-3 was also analysed. In these selected matrices, we measured equilibrium P concentration (EPC_0) and P absorption kinetics. The results showed that the settling characteristics of similarly enriched particles were very different. This contests generally held assumptions about source equivalency and shows the important role played by sedimentation in lakes.

In laboratory conditions, physical parameters can reach their theoretical maximum, but in the water column of a real lake or reservoir other forces can play important roles, e.g. turbulence caused by lake mixing, wind or river jetting into thermally stratified layers and convective current caused by diurnal change in solar heating. In future, physical characteristics should be used together with sample P bioavailability determined directly via dual-culture assay or indirectly via chemical fractionation.

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TEMPORAL VARIATION IN THE P SOURCE FACTOR IN A SMALL GRASSLAND WATERSHED

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The P source factor is an essential component of the P index, which is a measure of the risk of P loss from land to surface waters. The P source factor is usually estimated from the concentrations of P measured in soil, taking into account the inputs of P to the soil via organic and inorganic fertilizers and also the method of application of these fertilizers. Obviously, the value will vary in fertilized soils because it will be strongly affected by fertilizer application and by plant growth cycles. However, little is known about how the P source factor varies throughout the agricultural year in cropped land, where large amounts of P may be transported from the soil to surface waters. We investigated the variation in the P source factor during the period of maximal plant growth (March- October) in the Fonte Espiño-Rego de Abellas basin (Galicia, NW Spain). The basin covers an area of 772 ha and the main land uses are grassland (both natural and planted with a mixture of graminaceous and leguminous plants) and forest (reforestation with *Eucalyptus globulus* Labill and *Pinus radiata* D. Don.), with some small agricultural plots used for domestic purposes. Between March and October, soil samples were obtained fortnightly from 36 sampling points in the catchment (forest and grassland soils). Each sampling point (ca. 0.5 ha) was selected beforehand and considered representative of different areas. Composite samples comprising 10–15 individual subsamples were collected from the upper 0 to 5 cm of the soil after removing plant remains from the soil surface. The samples were analyzed for general soil properties and for inorganic P extractable with 0.5 M NaHCO₃, pH 8.2 (Pi Bic), according to Olsen et al. (1954).

The values of the P source factor varied little in the forest soils but varied widely in grassland soils throughout the study period. The soil quality therefore varied from low or very low to high or very high. Elaboration of P source factor maps enabled us to distinguish areas where the P source factor remained constant throughout the study period from areas where the factor varied widely. We also used the maps to predict what time of year the risk of P transfer from soil to water will be greatest.

POSSIBILITY OF INCLUSION OF PARTICULATE P LOSS IN THE ESTIMATION OF P SOURCE FACTOR

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Accurate estimation of the P source factor for the elaboration of a P index requires knowledge of the forms of P that move from soil to water. In most P indexes developed to date, only the inorganic P is taken into account, although erosion processes favor the movement of P associated with soil particles (PP) to water courses. During the elaboration of a P index for the Fonte Espiño – Rego de Abellas basin (Galicia, NW Spain), we found that inclusion of a parameter related to the risk of loss of PP from soils would improve estimation of the P source factor. However, at the time, we could not include this parameter in the index because it was not possible to assign categories to the levels of particulate PP as very little is known about PP, unlike other P-related parameters (available P, MRP). To address this problem, we analyzed the desorption of PP from soil to water, within 30 min and at two different ratios of soil to water: 1:100 and 1:10 (w:v), in a laboratory test involving 500 soil samples from the above-mentioned basin under different types of land use (forest, natural grassland and fertilized grasslands) and sampled at different times of year. We measured the PP as the difference between total phosphorus (TP) desorbed and the MRP. The amounts of PP desorbed varied widely (0.000-0.311 mg P L⁻¹ for the 1:100 ratio, and 0.000-1.620 mg P L⁻¹ for the 1:10 ratio). For both extraction ratios, the distribution of values (mg L⁻¹) fitted a Gaussian curve, so that different categories can be considered in relation to statistical parameters (20 % percentile, mean value, 80 % percentile):

	Very low	Low	High	Very high
Ratio 1:100	< 0.030	0.030 - 0.050	0.050 - 0.070	> 0.070
Ratio 1:10	< 0.100	0.100 - 0.200	0.200 - 0.300	> 0.300

We used these categories to classify the soils and found that the forest soils were mainly included in the low and very low categories, the natural grasslands in the low and high categories and the fertilized grasslands in the high and very high categories. All of the soils, independently of land use, displayed minimal risk of PP desorption during the summer and maximal risk during spring. The defined levels enable use of PP desorption to improve estimation of the P source factor, and they can also be used in regions that are similar to the Fonte Espiño-Rego de Abellas in terms of climate, soil type and land use.

SOIL SOLUTION PHOSPHORUS DYNAMICS IN SOILS ENRICHED IN THIS ELEMENT

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One of the signs of human settlement and activity on a particular area is an increase, often very large, in soil phosphorus (P) content. Urban soils, which are under constant and varied human impact, are especially susceptible to the accumulation of P compounds. In P rich soils, urban or agricultural, there is a high risk of P leaching. Phosphorus can be particularly easily leached from soils, which have large resources of readily soluble forms of this element. The soils of convent gardens in Krakow are especially rich in easy soluble forms of P. The medium responsible for transport of soluble components in the soil is the soil solution, which can be analysed by different methods. This study traced the dynamics of P content in the soil solution during two growing seasons. Soil solution was collected by an *in situ* method at a depth of 30, 60, 90 or 120 cm, and sometimes 170 or 180 cm, in the soil of selected convent gardens in Krakow using vacuum soil water samplers. The soil solution was sampled at least once a month, from April to November in years 2010 and 2011. The P concentration in solution was measured by a colorimetric method, simultaneously with soil pH and carbon content. The analyses revealed that the P concentration in the soil solution was very high, ranging from 4 to 83 mg P dm⁻³. At a given depth, the P content in the soil solution during the growing season was generally similar. In addition, the mean annual content at the vast majority of sites was not significantly different. However, at some sites a slight increase in P content in the soil solution was observed with increasing sampling depth.

FILTER SYSTEM FOR PHOSPHORUS IN DRAINAGE WATERS – A PILOT STUDY

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Many agricultural soils in Denmark have become highly enriched with phosphorus (P) and the majority of the agricultural land is tile-drained. This has created critical sources areas for P loss to the aquatic environment. Since agronomic mitigation options addressing P loss in drainage waters are limited and often take effect only after many years, end-off-pipe solutions are increasingly called for both by authorities and farmers. Such solutions have to be robust, easily manageable and cost-effective. We present the initial results from a drainage water filter system that has been installed in a drainage catchment with loamy soils in Eastern Jutland primarily to test P retention by a low-cost filter material under field conditions with variable hydraulic and P loads. Additionally, we explore lamella filters for removing sediment. This work is part of a larger research project investigating cost-effective filter technologies for nutrient removal from agricultural drainage waters in strategic landscape positions (<http://www.supremetech.dk/SUPREMETECH.htm>). The system consists of a series of connected chambers including support wells for sampling and flow measurements (Fig. 1, left). At the core of the system are two large 2-m diameter concrete wells. The first houses lamella filter cassettes for removal of sediment (Fig.1, middle); the second a cylindrical filter basket (Fig. 1, right) holding 2.3 m³ shell sand (DanShells) of the size fraction 2-5 mm. In a preceding laboratory study under controlled conditions, shell sand proved highly effective in retaining dissolved P under variable flow conditions. Water flows radially from the outside through the filter matrix. Flow is regulated and during peak flow runoff exceeding the hydraulic capacity of the system by-passes. The system has been in operation since September 2012, and at IPW7 we present the first results of the system's performance.



Figure 1. From left to right: installation of drainage filter system; lamella cassettes; basket with shell sand filter matrix.

FAST SPATIAL-TEMPORAL VARIATION IN IRON(III) REDUCTION AND PHOSPHORUS SOLUBILITY IN A SEASONALLY FLOODED DANISH WETLAND SOIL

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Wetland soils can act as sinks for phosphorus (P) from agricultural soils and fluvial sediments. However, the sorption of P is sensitive to the redox conditions in the soil, especially the degree of iron (Fe) reduction. When soils become flooded and anoxic, Fe(III) is reduced and P sorption decreases, but the relationship between Fe and P solubility under variable field conditions is not very clear. A 4 x 5 grid of sampling points at 15 m spacing was laid out in an Fe-rich meadow soil next to the formerly straight Odense River, Denmark, where the water course was re-established in 2003. The soil in the test area exhibited great variation, with 30±15% organic C, 469±313 mmol kg⁻¹ Fe oxides, 42±4 mmol kg⁻¹ Al oxides and 42±61 mmol kg⁻¹ P. The redox conditions were monitored by sampling on five occasions over an 11-week period from late March until early June 2011.

The degree of Fe reduction (DR_{Fe}, i.e. the ratio of soluble plus sorbed Fe(II) to total pedogenic, non-silicate Fe) and P solubility of the soil were studied in time and space. The highest average value of DR_{Fe} (76%) occurred at the beginning of April and it decreased to 36% within only nine weeks. The spatial variability was also high. The mean coefficient of variation of DR_{Fe} varied from 32% to 96% between samplings. The temporal and spatial variation in Fe and P soil solution concentrations was even higher. At the highest DR_{Fe}, average Fe(II) and P concentration in extract solution was 190 µM L⁻¹ and 24 µM L⁻¹, respectively and decreased to 40 µM L⁻¹ and 4 µM L⁻¹ under the most oxic conditions. DR_{Fe} was significantly correlated with P in solution ($R^2 = 0.83$). To assess the abilities of a wetland soil to retain P, it is essential to have a high sampling resolution over long periods of time. Our results indicate that the soil in the study is not an efficient trap for P under the current hydrological conditions. Phosphate-rich sediments deposited in the riparian zone during inundation events may be remobilised due to reductive Fe oxide dissolution, but whether the dissolved P re-enters the river was not investigated.

POTENTIAL SOIL P TRANSFER TO RUNOFF WATER IN AREAS FERTILIZED WITH ORGANIC RESIDUES

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Field scale P losses to runoff water from soils differing in profile development and fertilized with different sources of soil P were compared with losses measured in laboratory desorption experiments. The field experiment, which was performed in a Dystric Regosol area with 9% slope and 18 plots of 42 m² each equipped with a runoff water collection box, consisted in 3 repetitions and 6 fertilizer P (50 kg ha⁻¹) treatments: control, no P added (*C*); P mineral fertilization (*F*); cattle manure (*M*); dry fraction of pig effluent (*P*); dry fraction of duck effluent (*D*); dry fraction of pig effluent on bare soil (*BP*). Ryegrass was sown in November 2012 1 month after P was added. A P desorption experiment to a dilute electrolyte (0.002 M CaCl₂) in the laboratory was carried out with soil samples of each plot incubated for 90 days at 24°C. For desorption, a soil:solution ratio 1:1000 was used to mimic runoff conditions and the dissolved reactive orthophosphate (P_d) in the supernatant after centrifugation was determined. Ammonium lactate-P (AL-P) and Olsen P were determined in the soil every 3 months. After three months AL-P increased significantly from 37 ± 8 mg kg⁻¹ (at the beginning of the experiment) to 123 ± 120 mg kg⁻¹ with the addition of fertilizers. Considering the effect of fertilizers the *D* treatment resulted in significant higher ($p < 0.001$) soil P levels while there were no significant differences between *P*, *BP*, *M* or *F*. Runoff water samples showed no significant differences between treatments. The average value of P_d in all treatments (including *C*) was > 0.20 mg L⁻¹. A high variability in the volume of runoff water was observed (CV from 82% in *C* to 170% in *D*), which can be partly attributed to differences in solum depth and preferential flow pathways. In the laboratory desorption experiment, all P-fertilized samples had significantly higher ($p < 0.001$) P_d levels than control samples. The *D* treatment resulted in significant higher levels of P_d (0.30 mg L⁻¹) than the *P*, *BP*, *F* (0.05 mg L⁻¹) or *M* (0.03 mg L⁻¹), with no significant differences between the latter. No correlation between the P_d values found in the desorption experiment and the corresponding ones in runoff water was found. Thus, both soil profile features and P sources play an important role in soil P losses to runoff, which is difficult to assess by laboratory experiments.

ACCUMULATION, LOSSES AND ENVIRONMENTAL RISKS OF SOIL PHOSPHORUS UNDER INTENSIVE VEGETABLE FARMING

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Runoff (overland flow) is one of the main ways of phosphorus (P) transfer from soil to water. Heavy P application and multiple year-round rotations in vegetable plots result in strong P accumulation. Even on flat land, summer rainstorms in regions with a monsoon climate can cause surface runoff and P losses. Using selected vegetable plots in the Yangtze River Delta area, China, this study: i) determined accumulated P and P fractions in the soil; ii) determined P losses and P fractions in runoff under simulated rainfall of 60 mm/h; and iii) evaluated the risks of soil P entering water environments. The rainfall simulations were conducted on vegetable plots with different soil types, P levels, tillage and crop coverage and P concentrations and/or fractions in soil, sediment and solution were analysed.

After 20 years of vegetable cultivation, soil total P (TP) increased from 600-800 mg/kg in conventional plots (rice-wheat rotation) to >4000 mg/kg. The main increase was in inorganic P (IP), which comprised more than 80% of TP, regardless of soil type. Among IP fractions, soluble P and aluminium-bound P (Al-P) increased with increasing years of vegetable cultivation. Soil coverage tended to delay the formation of runoff. Tillage enhanced the content of sediment in runoff, but decreased the amount of P in sediment. Occluded P and Ca-bound P in sediment increased with intensive vegetable growing, while Al-P and Fe-bound P decreased compared with source soils, implying more immobile P fractions in sediment. The content of P in solution significantly increased with increasing accumulated P in soil, especially on Stagnic Anthrosols, from trace in conventional plots to >2 mg/L. There was a strong linear relationship between Olsen-P and dissolved P in runoff.

Although there was more immobile P in sediment, much more P in solution was transported to surface water from soil, indicating great risks to the aquatic environment. To keep P below the permissible level specified in national surface water standards in China (0.2 mg/kg), Olsen-P would be need to be under 100 mg/kg, but in most soils studied with >5 years of vegetable cultivation it exceeded this level. The best ways to order to control P losses to surface water include building ecological ponds around vegetable plots or changing to staple crops such as rice and wheat.

HOW USEFUL ARE COMPLEX PROCESS-BASED CATCHMENT-SCALE PHOSPHORUS MODELS?

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For many freshwater bodies, reducing phosphorus (P) concentrations is crucial for obtaining good ecological status, as required by the Water Framework Directive. How to achieve these reductions is a complex problem, and catchment-scale models are increasingly being used as tools to explore P dynamics, to evaluate the likely effectiveness of river basin management plans, and to predict responses to changes in land use and climate. However, for model output to provide a useful contribution, models must be shown to perform acceptably.

This study investigates the ability of an increasingly-popular model, INCA-P, to simulate in-stream P concentrations in a diffuse pollution dominated Scottish catchment. Preliminary results from manual and automated model calibration (the latter using Bayesian methods) are presented. Manual calibration resulted in acceptable model fits for suspended sediment and dissolved P species, but not for particulate P. Several parameter sets produced equally good fits and differentiating between these requires data on the internal workings of the system, unavailable for most catchments. Only 40 of 112 parameters could be included in the auto-calibration, and choosing which to include introduces an important element of subjectivity into the analysis. Potential areas for model simplification are highlighted.

Key conclusions include: (1) INCA-P can adequately simulate in-stream dissolved P concentrations in the study area, but with standard monitoring data it is hard to know whether the right processes are dominating. This limits the usefulness of the model; (2) Automated model calibration techniques and uncertainty analyses are vital, but may provide an illusion of robustness; (3) Simpler models are needed to enable full uncertainty analyses to be carried out and to make model hypotheses more testable; (4) Complex models such as INCA-P are useful tools for summarising current knowledge, but care must be taken in interpreting scenario analyses. Model sensitivities and limitations must be properly understood and communicated before output is used to inform land management decisions and policy.

PHOSPHORUS AND PARTICLE RETENTION IN CONSTRUCTED WETLANDS – A CATCHMENT COMPARISON

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Seven constructed wetlands, situated in agricultural areas in the south of Sweden, were investigated for sediment accumulation and phosphorus (P) retention, and factors affecting the efficiency. The selected wetlands are situated in areas dominated by clay or heavy clay soils. National monitoring and estimations have shown that agricultural areas dominated by such clay soils have high P losses to waters including to the Baltic Sea. The aim of the study is to quantify the function of wetlands as sinks for the P lost from catchments with such soils. The accumulation of particles was measured once a year using sedimentation plates (40×40 cm) placed on the bottom of the wetlands. Soil and P retention was estimated from the amount of sediment and P accumulated on the plates, related to both wetland area and the area of the catchment. Here annual soil and P retention is presented after two years investigation. In all wetlands there was an annual net sedimentation of particles, but there was a large variation, both between wetlands and between years. Sediment retention varied widely between 12 and 200 tons ha⁻¹ yr⁻¹, and P retention varied between 25 and 200 kg ha⁻¹ yr⁻¹. In some wetlands there was a significant relationship between sediment accumulation and distance from inlet, with a decrease of dry weight from inlet to outlet. Most of the wetlands with this sedimentation pattern were long and narrow. There was a strong correlation between P retention and soil net sedimentation (linear regression; R²=0.92, p=0.000). P retention data was used together with wetland and catchment characteristics in a principle component analysis (PCA) in order to identify factors that may contribute to the overall P retention efficiency in these wetlands. The factors included were the ratio of wetland area to catchment area, the wetland length to width ratio, and various catchment characteristics, e.g. soil type, average slope in catchment and land use. Preliminary results from the statistical analysis demonstrate that none of these wetland and catchment characteristics affected P retention efficiency alone.

Our results indicate that the design of the wetland may be more important than its placement in the catchment. In order to obtain maximum P retention, one has to facilitate sedimentation in the wetland itself.

CATCHMENT MODELLING IN TWO AGRICULTURAL CATCHMENTS – DO LOCAL INDATA IMPROVE MODELLING AND WHAT DYNAMIC AND SPATIAL PROCESSES CAN BE ESTIMATED BY MODELLING?

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Two agricultural catchments in the county of Östergötland (Skenaån (160 km²) and a small catchment (8 km²) named HE in this paper) were intensively monitored in order to investigate changes in the concentrations and transport of nutrients (phosphorus (P) and nitrogen (N)). An additional aim was to assess how well the Hydrological Predictions for the Environment (HYPE) catchment model, which calculates hydrological variables in daily time-steps and water chemistry, reproduced the measured results when using more local data than the national S-HYPE model. These local data included water discharge, crop type, precipitation, sewage from rural households, soil texture, fertilisation regime and nutrient pools in the soil. Measurements of water flow and meteorological data were performed in the two catchments during 2009-2011. Grab samples were collected on occasions that represented various water flow regimes. During snowmelt, automatic water samplers were placed at strategic locations in one of the catchments, taking samples every third hour in order to capture the movements of nutrients during high flow. Two locally calibrated HYPE models with local indata were then used to generate concentration data.

Some of the preliminary results from monitoring were that: 1) Rapid changes in total P (TP) concentration (from 28 to 220 µg L⁻¹ in 24 hours) occurred during snowmelt; 2) there was no obvious relationship between water discharge and nutrient concentration, and 3) there was great seasonal variation in nutrient concentrations. At some sampling points, summer TP concentrations exceeded 2000 µg L⁻¹. Some preliminary results from HYPE modelling with local data were that: 1) The best model performance in relation to measured data was obtained for water discharge, while the model was less successful in modelling nutrient concentrations, and 2) model performance was not improved by adding local data, except local precipitation, but it was very important to achieve good calibration of the model. These results help understand nutrient transport and leakage, and reduce uncertainties in catchment modelling.

EVALUATION OF PHOSPHORUS NUTRITION INDEX AS A TOOL FOR P NUTRITION DIAGNOSIS IN PERMANENT GRASSLAND

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Management of mineral resources is a priority when developing sustainable herbage production systems where economic and environmental issues are the main considerations. In this context, accurate P management within farming systems based on grass production is an important goal because P is often growth-limiting. For that purpose, efficient and accurate tools are required for P nutrition diagnosis and fertilizer management accordingly. The main purpose of this study is to test the relevance of Phosphorus Nutrition Indices (PNIs) for (i) P nutrient status diagnostic in grassland, (ii) evaluation of the impact of P limitation on dry matter yield production (iii) identification of over fertilized grasslands.

This work relies on a network which gathers 5 long term (> 12 years) field experiments which aim to study the effects of N supply, with and without P fertilisation and frequent defoliation, on soil fertility evolution and changes in vegetation. The experiment sites are located in France (Gramond and Ercé), Switzerland (Petite Ronde), Romania (Dealul Sasului) and Canada (Lévis). For each site and year, the Relative dry matter yield (RDMY) is calculated for the first growth cycle as the ratio of the average DMY measured on P limited treatment plots (N1P0) to the maximum DMY measured on the optimum treatment plots (N1P1). N and P concentrations measured in forage are used for PNI calculation according to Duru and Thélier (1997). PNIs measured for the 5 sites confirm that, over years, the cumulative effect of treatments has differentiated P gradients whose amplitude varies according to sites: in Ercé PNI varies between 57 and 123, whereas the range is narrower in Lévis where PNI varies between 83 and 107.

Under limited P nutrition status, (PNI<100) we obtain a unique and significant relationship between RDMY and PNI, for the 5 sites together, which allows accurate evaluation of the impact of P limitation on grassland yield. On the opposite, P luxury consumption (PNI> 100) is identified on Gramond site, on treatment plots with high positive balances.

Overall, our results confirm, over a large range in soil, climate and vegetation conditions, the general value of PNI as a pertinent tool for P nutrition status evaluation in managed grasslands and environmental risk evaluation associated with extreme PNIs values.

COMPARISON OF PHOSPHORUS RUNOFF FROM A KOREAN RICE PADDY WATERSHED DURING STORM EVENTS BETWEEN THE GROWING AND NON-GROWING SEASONS

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We compared phosphorus runoff characteristics in runoff from a 23.4-ha predominantly paddy field watershed during six storms between growing and non-growing seasons. The mean annual precipitation over 30 years (1982–2011) is 1239 mm; approximately 77% of the annual precipitation falls in the growing season (late May to mid-October). The rice paddy is shallowly flooded in the growing season but is dried up in the non-growing season. Water samples and discharge measurements for runoff were taken at 2- to 6-h intervals per event. Runoff occurred during non-growing season when rainfall exceeded about 35 mm, which rarely falls during the non-growing season. Mean runoff ratio of storm events in the non-growing season was much lower than that in the growing season. Overall, total phosphorus (TP) and phosphate phosphorous ($\text{PO}_4\text{-P}$) concentrations in runoff water increased with discharge, irrespective of season. However, the flow-weighted mean concentrations of TP (0.50 mg L^{-1}) during the non-growing season were much higher than those (0.16 mg L^{-1}) during the growing season. Moreover, the particulate P is the dominant form (56%) of P loss in runoff during the growing season, whereas the dissolved P is the dominant form (70%) during the non-growing season. The latter may be because mineralization of P at the thin upper soil increases when soil dries during the non-growing season. The degree of soil drying may be a major factor controlling dissolved P release from the paddy field watershed. The phosphorus load from the rice paddy watershed during the non-growing season was relatively high despite a small amount of runoff. Therefore, the phosphorous loss during the non-growing season should be considered to estimate the phosphorous load of rice paddy watershed.

WETLAND RESTORATION - A NEW MODEL FOR PREDICTING PHOSPHORUS RELEASE RATES

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Restoration of wetlands on reclaimed agricultural lowland has been recognized as one of the most important mitigation options in fulfilling the quality goals of the European Water Framework Directive. An increasing number of studies have called to the attention that wetland restoration on former agricultural soils may result in P release. Despite the high priority of wetland restoration there is a serious lack in understanding the fate of P following wetland restoration, and predictive model tools are highly needed.

In the Danish Strategic Research project MONITECH, one of the major objectives was (i) to investigate key parameters controlling the fate of phosphorus following restoration of wetlands on former agricultural land, and (ii) to develop models predicting P release rates based on key parameters. Soils from 31 lowland areas were analyzed for a wide range of key geochemical parameters. Soil analysis demonstrated very large variations in all parameters e.g. carbon contents varied from <1 to >40%, oxalate extractable P (P_{ox}) from 20-5000 mg kg⁻¹, oxalate extractable Fe (Fe_{ox}) from 80-75000 mg kg⁻¹ and variation in bulk density from 150-1400 kg m⁻³. Batch incubation experiments demonstrated significant different responses to rewetting in terms of Fe(III)-reduction and P mobilization. Statistical analysis revealed that the soil $Fe_{BD}:P_{BD}$ -molar ratio (BD – bicarbonate-dithionite extractable), and bulk density turned out as best predictive parameters. To evaluate these results, and to further develop a model quantifying phosphorus release rates during conditions of convective flow, a column experiment simulating continuous upward percolation of discharging groundwater was performed on intact soil cores from selected soils. The column experiment confirmed the initial conclusions that the soil $Fe_{BD}:P_{BD}$ -molar ratio controls the P release rate during anaerobic infiltration. However, the column experiment also revealed that the P release rate at a specific $Fe_{BD}:P_{BD}$ -molar ratio directly correlates with flow-rate in diffusion rate-limited systems, while this was not the case for reduction rate-limited system. Based on these results an empirical model predicting the P release rate from the soil $Fe_{BD}:P_{BD}$ -molar ratio and water discharge, has now been developed and operationalized as part of the new Danish guidelines for predicting the impact of wetland restoration on phosphorus dynamics.

DRAINAGE FILTER TECHNOLOGIES TO MITIGATE SITE-SPECIFIC PHOSPHORUS LOSSES

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Drainage losses of phosphorus (P) contribute to an estimated load of 33% of total agricultural P losses in Denmark. Mitigating agricultural P losses is challenging, as critical P losses are only a small fraction of actual soil P contents and not directly related to fertilizer P input. Targeting high risks areas of P loss and applying site-specific measures therefore seems a more cost-efficient approach. The Danish Commission for Nature and Agriculture has now called for a shift of paradigm towards targeted mitigation and development of new, cost-efficient technologies to mitigate site-specific nutrient losses in drainage.

The “SUPREME-TECH” project (2010-2015), funded by the Danish Strategic Research Council, aims at providing the scientific basis for developing cost-effective drainage filter technologies to retain P in agricultural drainage waters. The project studies different approaches of implementing the drainage filter technologies including surface-flow constructed wetlands, subsurface flow constructed wetlands, and drainage well filters (www.supremetech.dk).

We will present results on P retention from (i) controlled column experiments with permeable filter substrates, and (ii) a full-scale surface-flow constructed wetland. In the former, various natural and industrial P filter substrates have been tested for their ability to reduce inlet P concentrations to below environmental threshold values ($<0.05 \text{ mg P L}^{-1}$) at variable phosphorus loads, hydraulic retention times, and flow regimes. Based on laboratory experiments and field scale monitoring, the different filter technology approaches will be compared and evaluated from a case study perspective.

UPSCALED APPLICATION OF SACHTOFER PR AS PHOSPHATE-BINDING FILTER

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We studied phosphorus (P) -binding potential of an industrial product Sachtofer PR. The P retention by the material was first tested in laboratory, by using a flow-through set-up and then on a meso scale, under variable flows and P concentrations. In addition, a P-sorbing barrier was installed in a ditch, receiving water from a sedimentation pond which drains an agricultural cropland of about 17 ha.

Sachtofer is a gypsum-rich material, with total Fe content of 10%. In the laboratory flow-through tests, we used fresh and pre-leached materials. During pre-leaching the fresh material was immersed into water to reduce the supply of Ca^{2+} and OH^- ions since they control dissolved P concentration in water solutions. To recognize the P retention mechanism, P-saturated material was equilibrated in solutions with variable pH. The ability of the P-saturated material to release P was assessed in one-month water extraction. The fresh and pre-leached Sachtofer showed high P retentions of 6.8-20 mg g^{-1} . As supported by the pH-manipulation tests, precipitation of Ca-phosphates occurred first, followed by sorption of P to Fe hydroxide surfaces.

In the meso-scale experiment, about 20 kg of Sachtofer were placed in a flow-through column which was fed for a period of 10 months. The influent P concentration mostly remained below 3 mg l^{-1} while the retention time within the column was 20 min. Initially, the material retained about 90% of the phosphates and finally the efficiency decreased to 7%. The filter retained 46% of the introduced P mass, exhibiting P retention of 3.2 mg g^{-1} . The maximum P retention was 30% when decreasing the retention time below 10 min.

The efficiency of the ditch filter, with a volume of about 6 m^3 , has been monitored since August 2010. The dissolved P concentration in the water varied between 50 and 300 $\mu\text{g l}^{-1}$. During the 3-year period, the filter retained 0.44 kg of P which is 28% of the dissolved P mass that entered the structure. In the first year, the barrier removed 53% of the dissolved P mass whereas 15% during the last year. The main challenges throughout the test included treating high flows and minimizing preferential water flows within the barrier.

Sachtofer is efficient in treating waters with variable P concentrations. However, its high price (100 € Mg^{-1}) shifts the focus towards applications that would receive high P inputs.

PHOSPHORUS, AGRICULTURE & ORGANIC WASTE: A DANISH P BALANCE

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The flows and stocks of phosphorus have been examined on a national or supra-national level in various recent studies. Agriculture is the main driver of phosphorus use today. However, P balances on a national scale, or even specifically on agricultural systems, have limited informative value; large differences exist in agricultural practice, corresponding to different soil types. Furthermore, waste management, by concentrating or transporting organic materials within the country, can potentially remedy inefficiencies in P use.

We draw on statistical data from trade, waste, Danish fertilizer accounts, and the national cadaster (Kvadratnet) to establish a model of flows and stocks for Denmark; 3 regional subsystems for the processes “agriculture” and “waste management” based on pronounced differences in agricultural practice are established.

Two regions with significantly different soils and agricultural production (clay soils/crops in Zealand, sandy soils/animals in Northern Jutland) will be examined in detail, with a third region (Fyn, Mid- and Southern Jutland) combining these characteristics within the region. Different soil phosphorus concentrations translate into different transfer coefficients and phosphorus stock dynamics in agriculture-related processes. The generation and flows of organic waste and sewage sludge will be mapped and presented as an integrated part of the Material Flow Analysis (MFA).

We establish a quantitative phosphorus balance on a spatially explicit level. Based on this, existing inefficiencies in current agricultural phosphorus use (e.g. unnecessary manure or mineral fertilizer application) can be identified.

Surpluses of mineral fertilizer likely exist especially in areas with mixed animal and crop production, due to the additional application of manure. We evaluate possibilities for improved waste management regarding nutrient recovery from organic waste and sludge and further substitution of mineral fertilizer based on the MFA model. We expect to find that the system yields significant potential for balancing supply and demand for phosphorus as a resource, while decreasing the use of mineral fertilizer.

PHOSPHORUS RETENTION AND SEDIMENT RESUSPENSION IN CONSTRUCTED WETLANDS – A METHOD COMPARISON

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Three wetlands (Bergaholm, Skilleby and Wiggeby) constructed in agricultural catchments in central Sweden were investigated for their function as particle and phosphorus (P) traps. The wetlands had similar area (0.06-0.08 ha) but varied in shape and in relative size to the catchment area (0.05-0.32 %). Sedimentation of particles and associated P has been shown to be the main retention process in wetlands that receive high load of particulate P. The aim was to evaluate two methods of estimating particle and P retention; I) inflow-outflow balances and II) P in accumulated sediment. Furthermore resuspension of accreted sediment was investigated.

Water flow was measured and water samples were taken at the inlet and outlet of each wetland. Sedimentation on plates representing net sedimentation was sampled once a year and sedimentation in traps (gross sedimentation) three or four times a year. Particle and P retention, as well as resuspension, was estimated for three hydrological years August-July 2009/10 – 2011/12.

The hydraulic load and sedimentation varied widely between wetlands and years. Average particle retention based on inflow-outflow balances were approximately 80, 150 and 50 tons ha⁻¹ of the wetland area yr⁻¹ in Bergaholm, Skilleby and Wiggeby respectively, while the particle retention based on accumulated sediment on the plates were lower, approximately 50, 20 and 10 tons ha⁻¹yr⁻¹. Net sedimentation increased with increasing gross sedimentation. Between 70 and 89 % of the sediment was resuspended in these small wetlands. The estimated mean P retention was approximately 80, 60, 10 kg ha⁻¹yr⁻¹, based on P net balance from water sampling and approximately 70, 20 and 10 kg ha⁻¹yr⁻¹ based on sediment plates. The annual P retention varied from a net release of -5% to trapping 47 % of the P losses from the upstream agricultural fields (0.1-1.1 kg P ha⁻¹ yr⁻¹).

The correlation between the two methods were relatively satisfactory for P retention ($R^2=0.7$) but weak for particle retention ($R^2=0.4$). These preliminary results indicate that sedimentation plates can be an alternative for estimating P retention in wetlands to the more expensive method water sampling at the inlet and outlet of a wetland.

THE LEIBNIZ SCIENCECAMPUS „PHOSPHORUS-RESEARCH-ROSTOCK“ – A NEW MULTIDISCIPLINARY RESEARCH PLATFORM IN NORTHEAST GERMANY

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The Leibniz Association and the University of Rostock (Germany) have founded the ScienceCampus Rostock „Phosphorus-Research-Rostock“. This novel research platform, co-funded by the Leibniz Association, the University of Rostock, and the Federal State of Mecklenburg-Western Pomerania, aims at solving urgent problems linked with the utilization of phosphorus (P) and its compounds in industrial, agricultural and environmental processes or cycles. It combines the expertise of researchers from five institutes of the Leibniz Association (Leibniz-Institute for Baltic Sea Research (IOW), Leibniz-Institute for Catalysis e. V. at the University of Rostock (LIKAT), Leibniz-Institute for Farm Animal Biology (FBN) Dummerstorf, Leibniz-Institute for Plasma Science and Technology (INP) Greifswald, Leibniz-Institute of Plant Genetics and Crop Plant Research (IPK) Gatersleben and from various faculties at the University of Rostock (Mathematic and Natural Sciences, Agricultural and Environmental Sciences, Interdisciplinary Research). Besides fundamental and applied research the cluster intends to develop new technologies and transfer these into economic applications. The research is organised in three clusters: (1) P-cycles and –fluxes in the environment, (2) efficiency and sufficiency of P-utilization and P-recycling, (3) P as element in and from catalytic processes. Additionally, the development of advanced analytical methods in P-research has been defined as cross-sectional task for serving and stimulating the above research clusters. Actually about 30 researchers are involved in this Leibniz ScienceCampus, who utilize the most advanced spectroscopic (e.g. synchrotron-based X-ray absorption, ultrahigh resolution mass spectrometry, Nano-SIMS), isotope and nuclear magnetic resonance) and modelling (across scales from quantum-mechanical to large scale environmental) techniques. The intention is also to establish European and world-wide research collaborations with some emphasis to the Baltic Sea region.

EROSION MAPPING IN FINLAND WITH RUSLE EROSION MODEL AT SCALES 100 M AND 2 M: CRITICAL SOURCE AREAS

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Erosion is a significant carrier of phosphorus to water bodies on clay soils of Southern Finland. This presentation demonstrates results of RUSLE based maps of soil erosion risk with two scales: 100 m and 2 m. The goal of our project is to estimate the erosion risk of fields (t/ha/year) for Finland and show calibrated results on the map. The Revised Universal Soil Loss Equation is: $A = R * K * L * S * C * P$, where A = Mean annual soil loss t/ha/y, R = Rainfall erosivity factor, K = Soil erodibility factor, L = Slope length factor, S = Slope factor, C = Cover management factor, P = Support management factor. The first, uncalibrated model of the Baltic Sea Drainage basin has a resolution of 100 m. For R, the precipitation data of World Climate 1 km grid was used: $R = [38.46 + (3.48 * P)]$, where P is the average annual rainfall (Lo et al. (1985)). The erosion factor K was estimated from European Soil Database 2 by using the same procedure as in Italian USLE-based erosion map. Finnish clay soils are qualified as Stagnosols instead of Cambisols in WRB 2006 and they can be vulnerable to dispersion erosion, which is not considered in present K-values. Length Slope factor (LS) was evaluated from Digital Elevation Model. It was a combination of CGIAR SRTM-DEM and DEM created from Soviet military maps. The Cover management factor was evaluated from Corine 2006 database and P-factor was not used. The second, calibrated model has a 2 m resolution: R was obtained from the FMI's precipitation data of 10 km grid according to Renard (1994): $R = 0.0483 * P^{1.61}$, where P is the annual rainfall. For the K the Finnish soil database 1:250K was used and K-values were taken from the Finnish ICECREAM model. The LS factor was calculated from 2 m DEM and the Cover management factor from IACS Register. P factor was not used. Results of both models were calculated on EEA's 1 km reference grid. 100 m Grid was ranked by relative values and 2m grid with absolute values t/ha/v and results were compared. In May 2013 the 2 m model covered 40% of the field area.

THE IMPACT OF ORNITHOGENIC INPUTS ON P TRANSPORT FROM ALTERED WETLAND SOILS TO WATERWAYS IN EAST MEDITERRANEAN ECOSYSTEM

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Agmon Hula in Northern Israel is a small (1.1 km²) artificial lake that was constructed in 1994 in the formally swampy area that was drained for farming in the 1950s. Following the establishment of this new aquatic system huge flocks of Golden Crane (*Grus grus* > 50,000) have begun wintering in the area which attracted over 400,000 bird watchers a year. To minimize crop damage a coalition of several organizations has begun initiated feeding in an area adjacent to the Agmon. The objective of this study was to evaluate the influence of this feeding operation on the P status of the altered wetland soils and waterways. We installed a series of shallow wells at two depths (40- & 90 cm) between two major waterways and monitored the hydraulic heads and collected groundwater samples for elemental analyses. We collected five soil cores and four sediment samples from the waterways and conducted sequential P extraction. We found significant increase in groundwater SRP (> 0.5 mg l⁻¹) in 2010 compared with P concentrations collected in the period prior to the feeding (SRP ~ 0.05 mg l⁻¹). We found significant decrease in Fe(II), Ca, and SO₄ concentrations in the shallow groundwater in 2010 (15-, 100-, and 20 mg l⁻¹ respectively) compared with the period prior to the feeding (60, 700, 200 mg l⁻¹ respectively). A shift in P fractionation from mostly inorganic P before the feeding to organic P and significant increase in total P (~ 4000 mg P kg⁻¹) was also observed. The birds input to the feeding area west of Lake Agmon were estimated to be around 600 to 700 kg P per season. Once the birds leaving the area for their nesting period in Northern Russia the feeding area of 0.8 km² is quickly covered by lush pasture weeds that being harvested by the end of the summer for cow feeding. Vegetation analysis showed that the plants contain approximately 1925 mg P kg⁻¹. On the basis of groundwater hydraulic head analysis, number of wintering birds, P content in bird excrement and P in the plant dry material we concluded that about 0.5 to 0.8 ton of P is being removed by plant harvesting with little impact on waterways. This finding supports the current sustainable eco-tourism practices in the middle of intensive farming area.

CATCH CROPS FOR PHOSPHORUS UNDER COLD CLIMATE

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Catch crops (cover crops) are efficient in reducing nitrogen leaching and preventing soil from erosion when there is otherwise no crop cover, but relatively little has been reported on their efficiency in mitigating phosphorus (P) leaching. Instead, in regions with winter frost like Nordic countries, a great concern is that catch crops may act as a source of P losses to water because P can be released from plant tissues after frost. Two studies were conducted to examine eight potential P catch crops; chicory (*Cichorium intybus* L.), cocksfoot (*Dactylis glomerata* L.), perennial ryegrass (*Lolium perenne* L.), red clover (*Trifolium pretense* L.), phacelia (*Phacelia tanacetifolia* L.), white mustard (*Sinapis alba* L.), and radish (*Raphanus sativus* L.) with the latter represented by both *R. oleiformis* and *R. longipinnatus*. One study was to investigate potential uptake of P by the catch crops in the greenhouse and leaching of P from the crop shoot and root materials after freezing-thawing cycles (FTCs). The other was a three-year study to examine uptake of P by these crops on three Swedish clay soils and P leaching from soil lysimeters both before and after FTCs. The catch crops took up 4-18 kg P ha⁻¹ in the greenhouse, on dependent of species. In the field, uptake of P by these crops was generally lower (0-6 kg P ha⁻¹), but when the soil P content was high they took up P at amounts (6-15 kg P ha⁻¹) comparable with in the greenhouse. The greenhouse study showed that all the P in catch crop plant tissues can potentially be released after severe freezing and that the potential P release was strongly correlated to total-P concentration in the plants. In the lysimeter study, the catch crops were not demonstrated to reduce P leaching before FTCs. Leaching of total-P increased after FTCs compared with before ($p=0.04$) and varied significantly with year ($p<0.0001$) and species ($p=0.04$). Ryegrass and radish (*R. oleiformis*) were the most sensitive species to frost in terms of causing the largest increase in total-P concentrations compared with the control. Chicory, cocksfoot and radish (*R. longipinnatus*) were the least sensitive crops and caused no significant increase in P leaching after FTCs. It is concluded that perennial ryegrass, commonly grown as a catch crop in the Nordic countries, may need to be replaced by new species to avoid causing risk of P leaching during winter.

A SOIL SURFACE COMPLEXATION MODEL TO DERIVE A P SORPTION INDEX FOR SCOTTISH SOILS

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The retention behaviour of phosphorus (P) in Scottish soils at a national scale has been investigated with the use of a model based on surface complexation theory, in order to predict the soil P sorption index (PSI). The PSI is required to refine fertiliser application rates and to inform water quality managers of soil properties related to potential P leaching losses. The retention of P was estimated by considering the adsorption of P by an generic Fe/Al (oxy)hydroxide and a phyllosilicate clay mineral surface. These processes were modelled with the CD-MUSIC (Charge Distribution MUlti SIte Complexation) model, using model parameters from the literature (e.g. Weng et al. (2011)). The model also includes the pH dependency of P sorption and the competitive effects of adsorbed Ca and organic carbon (OC). To facilitate modelling some simplification is required regarding the derivation of input parameters from routinely measured soil properties. Soil data used for the modelling consisted of acid ammonium oxalate extractable Fe and Al, % OC, pH, particle size and acetic extractable cations. The soil data was sourced from the second National Soils Inventory Scotland (NSIS-2) data set and analysis of archived soils (400 soils in total). The model has been used to produce the PSI data in a map format. For mapping, the soils were categorised according to 38 different soil associations (mapping units used by the Soil Survey of Scotland) and the average soil properties determined for each unit. P sorption was calculated with the model, and the 38 soil associations ranked according to their P sorption capacity into P sorption indices from 1 (very low capacity) to 5 (very high capacity). We believe this is the first time a surface complexation model has been used to map a soil function nationally. The map shows a close correspondence between PSI and parent material, with soils developed on basic igneous rocks (largest amorphous Fe content) having the greatest PSI (class 5). Large areas of class 1 in the north-west are mainly upland organic soils used for rough grazing. The information is currently being used to revise fertiliser application rates in relation to current soil P test values.

Weng, L. et. al. (2011). Environmental Science & Technology, 45, 8420-8428.

PHOSPHORUS USE EFFICIENCY BY RICE AND BEAN CULTIVARS MEASURED BY ISOTOPE TECHNIQUE ^{32}P

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Low availability of phosphorus (P) limits crop production worldwide, especially in the developing countries that have low input phosphate fertilizer. With the increasing global demand for food and shortage of phosphate rocks, it has become the need for the intensification of study for increase phosphorus use efficiency (PUE) of crops. An effective strategy for reducing the use of P fertilizers would be the development of cultivars that have higher capacity to grow under soils with low P availability. This study aimed to evaluate the PUE by rice and bean cultivars grown in Brazilian Savannah soil by the isotopic dilution technique, using the radioisotope ^{32}P . Sixteen rice and nineteen bean cultivars recommended for savannah region were compared in low level of P (20 mg kg⁻¹). The soil was Ultisols labeled with the radioisotope ^{32}P . The experiments were conducted in greenhouse in a completed randomized design with four replications. Seedlings were harvested 40 days after sown, the growth parameters measured were shoot dry weight (SDW) (g pot⁻¹), P-concentration in shoot (g kg⁻¹), P-uptake (P-concentration x dry matter) and specific activity of ^{32}P (Sa) (DMP µg P⁻¹). The Sa was used to verify the similarities among the cultivars of rice and bean with relation according to the PUE (lower Sa is greater PUE). Differences among the cultivars were compared using the t test ($\alpha = 0.05$). There were substantial variations in the growth traits, such as SDW, P-concentration and P-uptake under low-P condition to both crops. Based on values of Sa, the rice and bean cultivars were classified as: efficient, middle efficient and little efficient. Our results indicate that it is possible to select rice and bean cultivars recommended for savannah region with high PUE. The select of new cultivars with higher PUE could reduce P fertilizer input costs, decrease the rate of P losses (adsorption), and enhance crop yields. This coupled with best management practices will contribute to sustainable agricultural systems and encourages the expansion of the agriculture in low-P soils.

EFFECT OF SHELTERBELTS ON PHOSPHORUS AVAILABILITY IN ARABLE SOIL

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Midfield shelterbelts or windbreaks are a man-made element of the agricultural landscape. Planting shelterbelts is considered equivalent to afforestation in terms of protection factor and use of the environmental space. In certain topographical conditions, midfield shelterbelts in agricultural fields can function as barrier ecosystems owing to the high sorption capacity resulting from the presence of litter and nutrient uptake by growing trees, which act as a buffer for biogenic elements. This study assessed the influence of shelterbelts composed of black alder (*Alnus glutinosa*) on the spatial distribution of available phosphorus (P) content in an agricultural soil as a function of distance from the shelterbelt (up to 24 m). The soil at the site is a Vertisol, derived from tertiary clay sediments and soil samples were collected in spring and autumn 2012. In addition, plant material (alder leaves) was collected in litter traps.

Alder trees were mainly a source of carbon (C), nitrogen (N) and P. The P content in fallen alder leaves ranged from 636 to 747 mg kg⁻¹. Leaves were mainly deposited on the soil surface in the vicinity of trees and the highest “input” of P in fallen leaves was equal to 1.85 kg ha⁻¹ of pure P. The lowest available P concentration in soil was recorded in the zone immediately adjoining the shelterbelt (0-2 m) and the highest in the zones at 20-22 and 22-24 m distance. The P content in some samples collected from the zones situated between 2 and 12 m from the shelterbelt was also elevated. These results illustrate the mechanism of P adsorption in the soil under shelterbelts and the geochemical barrier activity of the trees, which take up elements and thus reduce their levels in the soil. Nutrient runoff from agricultural fields adjacent to shelterbelts could be limited in this way.

PHOSPHORUS LIMITATION OF BENTHIC ALGAE IN UK RIVERS

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Major reductions in phosphorus concentrations have been achieved in many rivers by limiting phosphorus inputs from sewage treatment works and agriculture. This comes as a result of EU-driven directives including the Urban Wastewater Treatment Directive, Water Framework Directive and the Nitrates Directive. Within the United Kingdom, however, these reduced phosphorus concentrations have not always been coupled with the expected ecological improvements. This suggests phosphorus concentrations are still in excess for algal growth.

A series of portable within-river flume mesocosm experiments (Figure 1) have been conducted in three contrasting rivers across the UK. The average soluble reactive phosphorus concentrations of these rivers ranged from 15 to 225 $\mu\text{g l}^{-1}$. These mesocosms allowed phosphorus concentrations in the through-flowing water to be either increased or decreased (using a novel iron-dosing technique) in order to determine the effect upon benthic algal growth.



Figure 1. Two sets of three flume mesocosms used in the experiments presented.

Results from these experiments were surprising and challenge the traditional belief that phosphorus is the main nutrient limiting benthic algal growth in the freshwater environment. In an oligotrophic river, increasing phosphorus concentrations by up to 10-fold did not have any significant effect upon total algal biomass observed on the artificial substrates at the end of the experiment. In addition to concentrating on phosphorus reduction, other factors affecting algal biomass need to be considered in order to achieve the 'good' ecological status required.

SOURCE AND TRANSPORT FACTORS INFLUENCING STORM P LOSSES IN SMALL AGRICULTURAL BASINS

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The relative risk of storm phosphorus (P) transfer to streams was assessed in two hydrologically contrasting catchments. Measured stream P concentrations and loads were compared with a static measure of diffuse P source (soil P) and a non-static measure of P transport (storm quick flow (*QF*)) to investigate whether critical source basins could be differentiated using these metrics alone.

Stream discharge and chemistry were measured at the outlet and two upstream locations in a well drained arable catchment (Arable A) and a poorly drained grassland catchment (Grassland B). Stream discharge was measured by applying customised stage-discharge relationships to sub-hourly stage data. Stream chemistry was measured every 30 minutes in four storm events using autosamplers and laboratory analysis at the upstream sites, and continuous bankside technology at the catchment outlets. Hydrograph separation was used to identify the *QF* component of discharge for each storm and P loads were calculated for the *QF* component. Areas of *connected high soil P* were identified as fields with soil P test at or above agronomic optimum that coincided with areas modelled to be of high hydrological connectivity.

In basins with similar percentage area of *connected high soil P* but with contrasting *QF* magnitude, mean P concentrations and loads were consistently higher in the basins which had the greatest *QF* magnitudes. This demonstrates that catchment connectivity as a whole, rather than connectivity of high-P soils only, determined relative P transfer between these basins.

In basins of similar *QF* response, mean P concentrations and loads again did not generally reflect trends in *connected high soil P*. In Arable A, basin mean P concentrations and loads again reflected trends in *QF* magnitudes. In Grassland B, mean P concentrations and loads did not consistently reflect trends in *connected high soil P* or *QF* magnitude. The dynamics of stream-water P concentrations and loads were instead storm dependent.

Where differences in hydrological dynamics were large, storm P losses were well differentiated by transport factors alone and regardless of differences in *connected high soil P*. Where hydrological dynamics are similar, non-static transport and source factors may be required to differentiate relative risk of storm P transfer from these agricultural catchments.

KINETICS OF P DEPLETION FOLLOWING SEQUENTIAL EXTRACTIONS WITH MEHLICH-3 AND OLSEN SOLUTIONS

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The efficacy of fertilization strategies, including no or minimum P applications for reducing the P content of P-saturated soils to levels adequate for agricultural production and environmental protection, could be improved by understanding how P is depleted over time. Our objective was to analyze the kinetics of soil P depletion following sequential extractions with Mehlich-3 (P_{M3}) and Olsen solutions (P_{OI}) while determining the contribution of inorganic (P_i), organic (P_o), and total P (P_T). Soil samples were collected in three long-term experiments in eastern Canada (L'Acadie, Lévis, and Normandin) and P was sequentially extracted 16 times, once daily, using either Mehlich-3 or Olsen solution. Initial P_{M3} and P_{OI} at the sites were in the order of Normandin > L'Acadie > Lévis while P_T was in the order of L'Acadie > Normandin > Lévis. The cumulative amount of P extracted after the 16 sequential extractions was in the same order as that of initial P_{M3} and P_{OI} . The extraction-dependent kinetics of P depletion of each soil was described by a logarithmic function ($Y = a \ln(N) + b$) for P_{M3} , and a power function ($Y = \alpha N^\beta$) for P_{OI} (with N as extraction number; a, b, α , and β are fitted parameters). The decrease of P_i following sequential extractions paralleled that of P_T while the Soil samples were collected in three long-term experiments in eastern Canada (L'Acadie, Lévis, and Normandin) and P was sequentially extracted 16 times, once daily, using either Mehlich-3 or Olsen solution. Initial P_{M3} and P_{OI} at the sites were in the order of Normandin > L'Acadie > Lévis while P_T was in the order of L'Acadie > Normandin > Lévis. The cumulative amount of P extracted after the 16 sequential extractions was in the same order as that of initial P_{M3} and P_{OI} .

RELATIONSHIP BETWEEN SOIL P AND THE P BUDGET FOR A GRASS SWARD WITH VARYING N APPLICATIONS

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The P budgets are used to quantify P flows at different scales, and to monitor soil P changes under field crops and different managements systems. Yet the sensitivity to N applications is poorly understood, particularly in the case of perennial grasses. Following the establishment of timothy in 1998 on a gravelly sandy loam soil, four rates of P (0, 15, 30, and 45 kg ha⁻¹) and N (0, 60, 120, and 180 kg ha⁻¹) were applied each year from 1999 to 2006 in a split-plot design with P applications as main plots and N applications as subplots. Soil test P was assessed using water (*C_p*) and Mehlich-3 (*P_{M3}*) extractions. Annual P budgets were calculated as the difference between applied P and annual P offtake, and they were then cumulated over the duration of the experiment. After eight years of annual applications, the values of cumulative P budget [Bcum] (-148 to 286 kg P ha⁻¹), *C_p* (0.13 to 0.94 mg L⁻¹), and *P_{M3}* (22.3 to 111.7 mg kg⁻¹) were affected by both N and P applications. Both soil test P indicators were linearly related to Bcum and a comparison of the regression coefficients indicated that this relationship was similar for all four N applications. Hence, for *C_p* and *P_{M3}*, a single linear regression with Bcum was obtained across the range of positive to negative Bcum values, including all N applications: *C_p* = 0.0015 Bcum + 0.3 (*r*² = 0.80, *P* < 0.001) and *P_{M3}* = 0.21 Bcum + 47.3 (*r*² = 0.84, *P* < 0.001). A positive or negative P budget of 100 kg P ha⁻¹ would then raise or deplete *C_p* by 0.15 mg L⁻¹ and *P_{M3}* by 21 mg kg⁻¹. We conclude that the relationship between P budget and soil test P change was not affected by N applications to timothy in this gravelly sandy loam soil. Validation of this result in a range of soils with varying physical and chemical characteristics is needed.

MANAGING LEGACY SOIL PHOSPHORUS IN GRASSLAND SOILS FOR AGRICULTURAL PRODUCTIVITY AND ENVIRONMENTAL QUALITY: A REVIEW

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Phosphorus (P) is a lithophile element that tends to accumulate in the solid phase at the Earth's surface and has a low water solubility. As P is a limiting nutrient for plant growth in most terrestrial systems, P in fertilizers has been a major factor underpinning global agricultural production in the 20th and early 21st centuries, including that from grassland. However, P is a costly farm input and it is also a finite mineral resource. Best agronomic practice is to maintain soil P levels at optimum over the medium-to-long term by managing P application and offtake. However, in some cases, soil P levels have been built up in excess of agronomic optimum due to P application driven by organic "waste disposal" or with the intention of building up a "bank" of soil P for future use. This has been associated with P losses to surface waters and impacts on water quality. Legislation, policy and best management practice advice in many countries has attempted to affect these legacy high P soils through a range of measures. In Ireland, for example, the Good Agricultural Practice measures, introduced in 2006 under the Irish Nitrates Action Plan, attempt to impose P deficits on soils with high P. National data shows that P fertilizer use declined by 55% on grassland soils between 2003 and 2008 and would suggest that soils with high soil P levels dropped from 30% in 2007 to 22% in 2011.

This paper presents a review of the international literature on legacy excessive P in grassland soils, management practices and policy measures to manage them, and changes in soil P in response to such measures. Consideration is given to both agronomic and environmental concerns. There are a number of factors in grassland production systems, and particularly dairy production systems based on grazed grass, that differ from other agricultural production systems. For example, offtakes are typically lower than in tillage and the recycling of P, either by animal deposition or spreading of manures, gives less control to the farmer. Important questions addressed include: how quickly do grassland soil P levels decline under situations of negative P balance?; what fractions of P control soil P decline?; what grassland management practices are important in determining where and how fast soil P levels decline?; and what scale is appropriate to implement practice change and monitor effects?

PHOSPHORUS MANAGEMENT, CHANGES IN SOIL P STATUS OVER TIME, AND STREAM P LOSS IN AN INTENSIVE DAIRY CATCHMENT

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Phosphorus (P) inputs are vital to maintaining agronomically optimal levels of production in intensive, grazed, grass-based dairy production systems. However, P is a costly input and is also a finite mineral resource and mismanagement of P inputs has been associated with P losses to water and impacts on water quality. This paper presents results from the Agricultural Catchments Programme; an integrated advisory/research programme working with stakeholders to assess the efficacy of Ireland's Good Agricultural Practice (GAP) measures in meeting the targets of the EU Nitrates and Water Framework Directives. Results are presented for field P sources, management and losses in the stream for a 7.6 km² catchment dominated by intensive, grazed, grass-based dairy production on well drained soils with permeable geology. Phosphorus management and source pressures were characterised in terms of field-scale P inputs and balances, recorded on-farm, and surface soil P status, assessed by sampling at a resolution of <2 ha across the catchment. Changes in soil P status over time were assessed by re-sampling the same sample areas after three years. Phosphorus loss was characterised in terms of P concentration and loads monitored continuously with high-resolution bank-side analysers at the catchment outlet. Mean fertilizer and manure P field inputs in 2011 were 26.5 kg ha⁻¹ (SD, 27.4). Most P (83 %) applied to grassland was in organic forms (slurry and farmyard manure). Peak P application was in February to May (63 %) with no P applied from late October to mid January. Initially, 30 % of soil samples had excessive P, but this decreased to 25 % over three years. Total stream P loss in 2010-2011 amounted to 0.54 kg ha⁻¹ yr⁻¹, with 62 % of this as reactive P. Results suggest that the GAP measures related to rates and timings of field P application are largely being followed, that soil P status would appear to be responding as intended, and that P losses in stream water are small relative to the quantity applied and, on balance, are likely to decrease over time in response to implementation of the GAP measures. This paper considers further implications for effectiveness of GAP measures, agronomically and environmentally, in intensive, grazed, grass-based dairy production systems, including appropriate scales for implementation and monitoring of GAP measures.

PLANT PHOSPHORUS AVAILABILITY IN LOW-TEMPERATURE BIOMASS GASIFICATION ASHES

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Low-temperature biomass gasification is an innovative and effective bioenergy conversion process able to cope with many different biomass feedstocks. In order to add value to the technology, the rest-product (ash) originating from the process was tested in a pot experiment for its suitability to be used as a fertilizer, with special emphasis on phosphorus (P) availability.

Ash material generated from two different feedstocks (straw and sewage sludge) was incorporated into a low-P soil at 0, 20, 40, 80, 120 and 160 mg total P kg⁻¹ dry soil. Positive control treatments receiving mineral P-fertilizer (KH₂PO₄) at the same rates were additionally set up. Initial Olsen-P values of the treatments were determined in soil samples. Pots were filled with 2 kg of soil (four replicates per treatment), and four spring barley (*Hordeum vulgare* L. cv. Iron) plants were grown in each pot in a growth chamber (24/12°C, day/night; 16-h photoperiod) for 8 weeks. At harvest, shoot dry weight and P content was determined.

Both shoot dry weights and initial Olsen-P values were similar in pots receiving sludge-ash at all P rates and in the control pots receiving no P. This indicates that P in the sludge-ash was unavailable to uptake by the plants. This is probably due to the presence of iron and aluminum in the sludge ash, originating from the precipitation of P from the wastewater treatment and forming poorly soluble Fe- and Al-phosphates in the ash. While the addition of 20 and 40 mg P resulted in significantly higher shoot dry weights with mineral P than with straw ash, no difference between the two P sources was observed at 80 mg P/kg. However, relating shoot dry matter and P content to the initial Olsen-P values indicates an underestimation of the phosphorus becoming plant-available from gasification straw ash compared with that from KH₂PO₄.

The results show the general suitability of ashes originating from the gasification process to substitute mineral P fertilizers, but also demonstrate a strong dependency on the feedstock used. An indirect ³³P dilution approach is being used in an ongoing experiment to determine more precisely the amount of plant P derived from the ash amendment. Results from this study will also be presented and discussed.

PHOSPHORUS SPECIATION IN GERMAN RIVERS DISCHARGING TO THE BALTIC SEA

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Phosphorus (P) is an essential nutrient for plants and contributes to the eutrophication of the Baltic Sea. The current P load of 489 t yr⁻¹ from the German catchment area (28,790 km²) originates to 61% from agriculture. Sustainable improvement of the ecological status of the Baltic Sea requires further reductions in nutrients and can be realised only by reducing diffuse sources. Phosphorus comprises three species: phosphate (PO₄), dissolved organic phosphorus (DOP) and particulate phosphorus (PP), which contains an inorganic (PIP) and organic (POP) fraction. To characterise phosphorus loads, total phosphorus (TP) and PO₄ are normally determined. The other fractions are not considered, but amount to 50-60% of the TP load. We targeted this gap by studying the entire speciation in order to obtain a better assessment of diffuse sources and to get hints for further reduction measures.

Measurements in various German rivers and streams in September 2012 showed considerably varying concentrations and composition, with PP in the range 0.2-7 µmol L⁻¹, which amounted to 18-79% of TP. DOP (range 0.12-1.1 µmol L⁻¹) constituted 4-31% of TP and PO₄ (range 0.25-3.8 µmol L⁻¹) constituted 12-68%. Temporal variations were evident from investigations along the lower part of the river Warnow in May and June 2011, with PP (0.23-3.07 µmol L⁻¹) being the dominant proportion, amounting to 4-83% of TP. PO₄ (0.48-2.85 µmol L⁻¹) was the second largest fraction, comprising 9-41% of TP in June, whereas in May it constituted only 13-13% (0.06-0.14 µmol L⁻¹). The proportion of DOP varied between 9 and 33% of TP (0.14-0.99 µmol L⁻¹). In recent studies, PO₄ concentration differed depending on whether the sample was filtered or not and was 2-7 times higher in unfiltered than in filtered samples, caused by release of PO₄ absorbed to particles due to the acid reagent used for determination. Thus we were able to distinguish between PIP and POP. In the upper river Warnow and its inflows, PIP exceeded the proportion of PO₄ by a factor of 1.3-4.1 and was the dominant fraction in two inflows, whereas POP was the largest fraction in the river itself. DOP constituted 12-28% of TP.

These initial studies demonstrate a high variability in TP composition. We next have to take the absorbed fraction into account. Changes during transport from the source to the river mouth and in coastal regions of the Baltic Sea will be the subject of future work.

TILLAGE SYSTEM EFFECTS ON SOIL PHOSPHORUS AVAILABILITY IN BRAZILIAN SAVANNA

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The major focus of global research into soil fertility in recent years has been adapting cropping and soil cultivation systems to exploit less available nutrients. Phosphorus is the most limiting nutrient for crop production in tropical soils. This work aimed to determine long-term management system effects on inorganic labile and moderately labile P fractions in an Oxisol from Mato Grosso State, Brazil. The managements are established since 2001: conventional tillage (CT - plough and harrow); no-tillage (NT) and an undisturbed reference area (Savanna). Soybean, corn and cotton are the main crops, and millet is the cover crop, with fertilizer inputs as recommended. Both tillage treatments received the same amount of P over the 11-year period. Soil samples were taken from 0-10 and 10-20 cm depths in October 2012. The inorganic P fractions were determined by a Hedley procedure. The NT system resulted in a greater accumulation of readily-available inorganic P-resin at both depths compared to the CT system (Table 1). This can be explained by the accumulation of organic compounds competing for adsorption sites in the soil. Surface-adsorbed P-bicarbonate was also greater in the NT system but only within the surface layer. However both tillage systems were effective in increasing labile P fractions in the topsoil compared to the original savanna. The majority of added P accumulated as moderately labile P-NaOH and P-HCl, but the effects of tillage system were not consistent. It highlight the benefits of NT system for maintaining optimum soil fertility.

Table 1. Inorganic P fractions of the Hedley's procedure with management in a Brazilian savanna soil

Tillage system	Inorganic P fractions (mg kg ⁻¹)			
	Resin	Bicarbonate	NaOH 0.1M	HCl
0-10 cm				
No tillage	37.5 a	36.6 a	197.7 b	20.4 a
Conventional	20,5 b	30,1 b	251,5 a	13,7 b
Savanna	8,5 c	29,2 b	106,3 c	1,1 c
10-20 cm				
No tillage	15,8 a	41,4 a	244,8 a	6,7 ab
Conventional	14,2 b	40,5 a	212,7 b	10,7 a
Savanna	4,1 c	14,2 b	95,0 c	2,2 b

PHOSPHORUS CONTENT IN RUNOFF FROM ARABLE LAND IN THE WESTPOMERANIA REGION OF POLAND

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The concentration of phosphorus (P) in the form of phosphate (P-PO₄) in surface runoff from arable land was determined on a medium intensity farm in the Westpomerania region of Poland in 2009-2012. Runoff samples from the field (area 40.86 hectares, slope ~5%) were collected in a special trough with dimensions 1.0 m length, 0.2 m width and 0.15 m depth, installed about 5 m above the bottom edge of the field. Soil samples were collected from the 0-5 cm layer in the part of the field above the trough. All water and soil samples were collected after intense rainfall events in the period 13 May 2011-3 July 2012. The P-PO₄ concentration in water samples was determined colorimetrically using an automated flow injection analyser. Plant-available P in soil samples was determined by the Egner-Riehm method. During the study period, agricultural practices in the field were recorded and, based on this, the 'soil surface' P balance was calculated. The crop rotation during the study period was oilseed rape, barley and triticale.

The P surplus at the soil surface varied between 0.5 and 97.6 kg P ha⁻¹, while the P content in the top 5-cm soil layer ranged from 12.6 to 288.2 mg kg⁻¹. The largest P surplus and highest P concentration in the soil were observed after manure application. The concentration of P-PO₄ in collected runoff was 0.49-17.97 mg L⁻¹ and was positively correlated with plant-available P in the top 5 cm of the soil ($R^2=0.723$). This correlation indicates that for economic and environmental reasons (protection of waters against eutrophication), excessive P enrichment of soil should not be permitted.

Overall, the results showed that: i) the amount of plant-available P in the topsoil fluctuated widely during the study period, possibly due to fertilisation and tillage operations; ii) the concentration of P-PO₄ in surface runoff was positively correlated with the content of plant-available P in the topsoil layer; and iii) the runoff from the field carried a risk of eutrophication due to its high content of P-PO₄.

IMPACT OF MINERAL FERTILIZER INTEGRATION WITH FARMYARD MANURE ON CROP YIELD AND SOIL P POOLS IN A LONG-TERM TRIAL IN GERMANY

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In this study the Hedley sequential P fractionation procedure was used to determine the size and changes in soil P pools after 50 years of applying different schemes of plant nutrient management to a continuous cultivation trial in a sandy soil in Germany. The schemes of plant nutrient management correspond to organic (farmyard manure (FYM) alone), Integrated (FYM + mineral fertilizers) and Balance (mineral N, P and K alone) applied to a crop rotation (potato-winter rye-oat). Balance fertilization (NPK) or application of FYM plus mineral fertilizer, mainly N, led to higher potato yields (5.74 t ha^{-1}) compared to unbalanced (-15 to -57%) fertilization or FYM alone (-12%), higher winter rye yields (5.1 t ha^{-1}) compared to unbalanced (-3 to -61%) or FYM alone (-51%) and higher yields of oats (3.97 t ha^{-1}) compared to unbalanced (-5 to 60%) or FYM alone (-56%). The P pools found in the control treatment when compared to those found in a forest near by the trial represent fertilizer and/or FYM applied previously to the establishment of the trial. In this context, for the control as well as the fertilized treatments (mineral with or without FYM), the NaOH_{in} P pool was the largest pool and acts as a sink for applied P and the residual-P pool the less affected. Application of 40 to $64 \text{ kg P ha}^{-1} \text{ y}^{-1}$ in form of mineral fertilizer and/or manure and the plant nutrient management affected the absolute concentration and proportion of all P fractions. Farmyard manure alone or in combination with mineral fertilizers increased drastically all inorganic-P pools but follows the same trend when compared to the mineral fertilizers only management. No further increment in NaOH_{in} fraction was observed in the FYM treatments. Application of P and K alone (omission of N) resulted in large increments of P in the NaOH_{in} and Resin-P, as result of low removal of P from low yielding crops. Application of N or N and K resulted in yield improvement, high P removal with the consequent reduction of all inorganic fractions. However, available P measured as resin-P or P_{CAL} remains at the same level of the control. Interestingly, both the NaHCO_3 and NaOH organic fractions were increased representing highly dynamic fractions to maintain P in soil solution. Balance (N,P and K) application were effective to improve yields but also to increase the available P to the medium level. The approach of integrated (FYM plus mineral fertilizers) or balance plant nutrient management proved to be the best practice of plant nutrient management to increase crop production per unit of area, to build up soil fertility and probably to minimize negative effects of nutrient loss on environment.

IS NUTRIENT RECYCLING A WAY TO DECREASE P LOSSES TO THE BALTIC SEA?

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The ecological state of the Baltic Sea and the inland waters has raised interest to reduce nutrient losses from anthropogenic sources. At an international level, both the Ministers of Environment of the Baltic Sea States and the Helsinki Commission decided that anthropogenic loading to the Baltic Sea should be reduced. Moreover, the main goals of the EU Water Framework Directive is to achieve a good ecological and chemical status for all inland and coastal waters by the year 2015 (WFD 2000), and the Marine Strategy Framework Directive aims at achieving or maintaining a good environmental status of European marine waters by 2020 (MSFD 2008). Further, Prime Minister Matti Vanhanen set a national target for nutrient re-cycling in Finland (Baltic Sea Action Summit 2010) recognizing the problem that nutrients are resources not to be wasted.

In Finland, water protection policy concentrates on agriculture, as it comprises the largest source of nutrients into water bodies. An agri-environmental subsidy program that states water protection as one of its main objectives has been in place in Finland since 1995. The programme is the main tool within Water Framework Directive (WFD) to control nutrient load from agricultural areas.

In this study, financed by the EU Baltic Sea Region Programme 2007-2013 (projects Baltic Manure and BERAS), we study the option of intensive nutrient recycling to reduce phosphorus loading to the Baltic Sea. Effect of nutrient recycling on phosphorus losses is modeled by an empirical model (Ekholm et al. 2005) in three study catchments representing the three typical agricultural production lines (crop production, cattle and pig husbandry) in Finland. The results are compared to prevailing phosphorus losses generated by the current agricultural policy.

Ekholm, P., Turtola, E., Grönroos, J., Seuri, P. & Ylivainio, K. 2005 Phosphorus loss from different farming systems estimated from soil surface phosphorus balance. Agriculture Ecosystems & Environment. 110, 266-278.

EVALUATION OF AGRI-ENVIRONMENTAL METHODS TO REDUCE PHOSPHORUS LOSSES AT FIELD AND CATCHMENT SCALE

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The main goals of the EU Water Framework Directive (WFD) is to achieve a good ecological and chemical status for all inland and coastal waters by the year 2015. In Finland, water protection policy focuses on agriculture, as it comprises the largest source of nutrient loading/runoff into water bodies. The Agri-Environmental Scheme (AES), which states water protection as one of its main objectives, has been in place in Finland since 1995. The AES measures are the main tool within WFD to control nutrient load from agricultural areas.

In this study (financed by EU FP7 project REFRESH) we simulate the effect of different cultivation and land use scenarios on phosphorus losses at catchment and field scales. The study area Yläneenjoki catchment (240 km²) is located in south-western Finland, and it is one of the intensively studied catchments of the follow-up programme of the Agri-Environmental Scheme. This area represents the main pig and poultry husbandry areas in the country. Agricultural fields cover one fourth of the catchment area. The main soil types are clay and till. The river Yläneenjoki discharges to the lake Pyhäjärvi.

We use the novel version of the dynamic, semi-distributed model INCA-P (Integrated Nutrients from Catchments – Phosphorus), which is based on equilibrium equations of phosphorus. Further, we use RUSLE analysis to show the erosion sensitive area in the catchment. In this paper we evaluate behavior of the INCA-P model against measured data at different scales from equilibrium studies at plot scale to calculated phosphorus loads from the catchment. Further, we evaluated different scenarios assuming different combinations of the extent of increasing the implementation of suitable AES measures with the purpose of decreasing phosphorus transport from the catchment.

REACTIVE BED FILTERS FOR THE REMOVAL OF P IN AGRICULTURAL RUNOFF – THE BINDING EFFICIENCY AT LOW CONCENTRATIONS INVESTIGATED IN LABORATORY AND FIELD EXPERIMENTS

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Bed filters filled with reactive media have become a new option to reduce the load of phosphorus (P) from agricultural land and farm activities. Several filter media have been tested however mostly for the use as sorbents in wastewater treatment. These include calcium and aluminum silicate minerals from natural origin and calcium and iron oxides from steelmaking slags, i.e. by-products. We performed short- and long-term bench-scale laboratory and pilot-scale field experiments to evaluate the removal efficiency of certain filter media under dynamic conditions with simulated and real agricultural runoff respectively. The commercial products Polonite[®] and Sorbulite[®] aimed for P recovery and recycling were tested in dual filter systems. Sorbulite was used in the first purification step because of its suggested ability to remove particles and organic matter, hence improving the conditions for sustained P removal by Polonite. Kaolin powder was added to the influent phosphate containing water in the laboratory experiment to simulate clay particles. The field experiments demonstrated good P removal efficiencies at concentrations from 1 to 600 $\mu\text{g L}^{-1}$. The filters were regulated to have a hydraulic retention time of approximately 30 minutes. The P removal of the initial 50% of water discharged to the filters was as high as 70-97%. The average removal efficiency ranged between 20 to 50%. The laboratory experiments clearly showed the negative influence of clay on the sorption capacity of the studied filter media. The filter life was more than halved when the water with a turbidity of 160 NTU was discharged to the filter. Filter behavior was investigated during peak flow events. The filter media had surprisingly high capacity to withstand the increasing flow and remain high in phosphorus sorption capacity. The rejuvenation ability by the filters during periods of no water flow was clearly demonstrated. XRD and ESEM-EDS were used to analyze samples of filter media that were in contact with agricultural runoff. The increased content of P was verified in the samples. As for other environmental samples previously investigated, the formation of amorphous calcium phosphates is suggested also here. It is concluded that Polonite and Sorbulite are promising filter media for efficient removal of P from agricultural runoff and farm wastewater but further investigations has to be undertaken on the technical design for their efficient use.

CAN LONG-TERM EXPERIMENTAL PLOTS DEMONSTRATE THE SUSTAINABILITY OF DIFFERENT PHOSPHORUS INPUTS?

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During the past 20 years, there has been a constant reduction in mineral fertiliser use due to price increases, environmental concerns and an increase in crop removal, leading to a phosphorus (P) budget decrease. These changes can lead to a decrease in soil P content, as already observed in some regions in Wallonia, and with P being an essential element for plant growth, this trend is not compatible with yield maintenance. Different studies have examined whether current cropping systems are sustainable, but long-term data are rarely available to understand the influence of cropping systems on soil behaviour or leaching risks or to choose adequate indicators of P. We studied two long-term fertilisation experiments to see whether they could provide answers to these questions for our soils.

The experiments were established in 1967 and 1959 to evaluate the effect of three P and K soil levels and different inputs on yield on a loamy soil at the Walloon Agricultural Research Centre in central Belgium. Soil samples were taken from the plots and analysed in the laboratory to determine different P indicators (degree of P saturation, total P, inorganic P, available P and water-soluble P) and edaphic parameters (total organic carbon (TOC), pH).

The results showed that all indicators were coherent with P levels and correlated with yields, but no differences could be found between fertiliser types. Zero P input caused a mean yield decrease of 7%, while doubling the amount of P removed by crops increased yield by 2% in comparison with plots with input corresponding to crop export. Thus the zero P-input option is rarely economically profitable in the long-term and providing double the amount of P removed is never financially sustainable. Analysis of deeper horizons did not indicate any substantial leaching into these levels, even in plots with double P inputs. Indeed, soil P content at depth in double P export plots was similar to that in plots with no P inputs or soils under forest cover.

So, to conclude, long-term experimental plots can provide the answers to different agronomic and also environmental questions. Moreover, they can help study the sustainability of cropping systems in real situations and determine appropriate P management.

DISTRIBUTION OF ORGANIC PHOSPHORUS FORMS IN SOIL AFTER 12 YEARS OF ORGANIC FERTILIZATION

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Phosphorus (P) is a limited resource and its efficient management is crucial in sustainable agriculture. The application of organic wastes as compost and manure to agricultural soils is important to replenish soil inorganic and organic P pools. Improving the understanding of the influences of these materials on soil P forms is necessary to increase the P utilization in cropping systems and thus avoiding P losses. Organic P forms in soil differ in their susceptibility to hydrolysis, and therefore in their availability to plants. Organic P forms in soil can be characterized by the addition of hydrolytic enzymes with different substrate specificities to classify enzyme-labile P into simple monoesters (monoester-like P), diesters (DNA-like P) and inositol hexakisphosphate (Ins6P- like P). This technique requires relatively little lab equipment and low costs compared to other techniques like ³¹P-NMR spectroscopy.

The objective of this study was to investigate the concentration of organic P forms (hydrolysable and non-hydrolysable) in soil after 12 years of different P fertilizer management in a field experiment. Cattle manure (CM) and biowaste compost (BC) were applied at a rate of 30 t per ha every three years beginning in 1998. Triple-superphosphate was applied once per year. A control without fertilizer (C) was established. The amount of P applied with inorganic and organic fertilizers was about 22 kg per ha and year. Soil samples of the topsoil (0-30 cm) were taken in autumn 2012 and hydrolysable organic P was estimated by enzyme additions to NaOH-EDTA soil extracts. Relatively little differences were observed between treatments in the concentration of organic P extracted with NaOH-EDTA, ranging from 194 to 235 mg P kg⁻¹. The proportion of hydrolysed to total organic P was lowest for the control (37%) and highest for CM (57%). CM and BC addition increased the amount of hydrolysable organic P in soil mainly due to a higher concentration of Ins6P- like P. This was the majority form of enzymatically hydrolysable P in all treatments and ranged from 59 (C) to 74 mg P kg⁻¹ (CM). Monoester-like P and DNA-like P were also detected but in a lesser extent and no differences between treatments were found.

AN INDOOR LYSIMETER STUDY OF FOUR CATCH CROPS AND TWO SOILS EXPOSED TO FREEZE–THAW CYCLES

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The P loading to the Baltic Sea is of great concern to the surrounding Baltic nations due to its effect on water quality. Agricultural nonpoint-source pollution is reportedly the largest contributor of P to this problem, contributing as much P as all other anthropogenic sources combined. Catch crops have been found to decrease leaching of nitrates into surface water and groundwater and are now also used to reduce P leaching. However, they also have the potential to increase P loadings to natural waters due to plant destruction during freezing–thawing events. An indoor lysimeter experiment was performed using a loamy sand soil (Nântuna) from Uppsala, Sweden and a silty clay soil (Brunnby) from Västerås, Sweden, with four different plant species applied: perennial ryegrass (*Lolium perenne* L.), honey herb (*Phacelia tanacetifolia* Benth.), chicory (*Cichorium intybus* L.), and oilseed radish (*Raphanus sativus* L.). These plants were exposed to simulated rainfall and freezing events in two separate experiments, one using 25cm topsoil columns with plant material added and one with plant material only. The sand and clay soils had significantly different control total-P leaching loads after all freezing events, with a mean of 0.32 kg ha⁻¹ for the clay and 0.88 kg ha⁻¹ ($P < 0.001$) for the sand. The combined (soil including plant material) total-P leaching loads from the clay soil were in the order: chicory (2.6 kg ha⁻¹) > ryegrass (2.3 kg ha⁻¹) > oilseed radish (2.2 kg ha⁻¹) > honey herb (1.3 kg ha⁻¹), with considerably smaller loads from the sand. Phosphorus losses were greater from the plant-only experiment, with chicory (51.7 kg ha⁻¹) > oilseed radish (43.2 kg ha⁻¹) > honey herb (18.4 kg ha⁻¹) > ryegrass (10 kg ha⁻¹), with between 38–67% of the cumulative total P leaching load from the four rainfall simulations lost after the first freezing event (second rainfall simulation). The results indicate that soil texture and plant choice can have a large impact on P leaching loads entering natural waters in cold regions and that soils act as an efficient filter for P released from catch crop residues.

THE RESIDUAL EFFECT OF DIFFERENT ANIMAL MANURES ON SOIL P DISTRIBUTION WITHIN THE LABILE AND MODERATELY LABILE HEDLEY P FRACTIONS

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This study evaluated the residual effect of adding different animal manures on soil inorganic (P_i) and organic P (P_o) transformations as determined by the Hedley P fractionation. Five animal manures of different origin, swine liquid fraction (SLF), swine solid fraction (SSF), poultry solid fraction (PLF), dairy liquid manure (DLM) and dairy solid manure (DSM), were added to a sandy loam Dystric Regosol with low P content (9.1 mg P kg^{-1} ammonium lactate P), sieved at 5 mm, to yield $53.2 \text{ mg P kg}^{-1}$. Untreated soil (U) was used as the control. After manure was added, maize was sown and grown for two months in 12 L lysimeter pots to re-equilibrate soil. Post harvest soil samples were collected and P extracted for labile fractions of the Hedley fractionation, cation and anion exchange membranes (CAEM), $0.5M \text{ NaHCO}_3$, and $0.1M \text{ NaOH}$. Inorganic P was determined in all extracts and total P (P_t) determined in NaHCO_3 and NaOH extracts after acid persulphate digestion. Organic P was calculated as the difference between P_t and P_i .

Results show that despite significant ($P < 0.001$) differences in the total amount of P recovered by the sum of CAEM- P_i , NaHCO_3 - P_t and NaOH - P_t fractions (86 to 140 mg P kg^{-1} in U and SLF treatments, respectively), the percentage distribution of P among these fractions was similar in the six treatments and no significant differences were observed. Proportionally, the CAEM fraction represented between 12 and 17% of extracted P_t , whilst the NaHCO_3 contribution varied between 28% and 33%, and the NaOH fraction represented more than 50% of the extracted P in all treatments. However, significant ($P < 0.001$) differences were observed between P_o and P_i in the NaHCO_3 and NaOH extracts. Manure addition led to significant increases in P_i , and proportional decreases in P_o , with more pronounced differences in treatments with liquid manures. The ratio of $P_i:P_o$ varied from 1:2 (U) to over 2:1 (SLF, PLF) in the NaHCO_3 fraction and from nearly 2:1 (U) to 6:1 (SLF, PLF) in the NaOH fraction. The results highlight the importance of P_o mineralization, particularly following liquid manures applications, in supplying longer-term (>2 months) plant available P_i . These facts are supported by significant ($P < 0.01$) net decreases in total P_o of SLF and PLF treatments, respectively -9.4 and $-11.3 \text{ mg P kg}^{-1}$.

SPATIAL DISTRIBUTION OF SOIL PHOSPHORUS IN AGRICULTURAL FIELDS

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Phosphorus (P) surplus in Danish agriculture has led to P accumulation in soils and later enhanced P losses to water causing eutrophication. Environmental issues and globally limited P reserves present an incentive for managing soil P resources more efficiently. The knowledge of spatial patterns of soil P may improve fertilizer use efficiency and aid the identification of source areas for P loss. Therefore, this project investigated spatial P distributions in relation to geomorphological processes, crop yield and soil conditions and examined the practicality of predicting P-zones for improved soil P testing.

Over 1000 soil samples were collected from the plough layer on grids in two fields in the central part of Jutland and analyzed for various soil properties. Yield data were obtained. Terrain attributes were derived from a 1,6 m digital elevation model. The k-means cluster method was used to delineate P- zones for different parameter combinations. Soil P was highly variable within the two fields with TP ranging between 258 - 1289 mg P kg⁻¹. The highest P concentrations occurred in concavities and areas with a high wetness index and terrain attributes explained 22-37% and 40-60% of the variation in Olsen P and TP.

Tillage erosion patterns were consistent with the spatial P distribution in both fields. Neither soil electrical conductivity, and hence soil texture, nor crop yield could explain patterns of soil P. P- zonation based on SOC reflected the spatial variation of P better than an arbitrary division into subfields. Therefore, this approach could improve soil sampling strategies for characterizing P status in fields of rolling topography.

IDENTIFYING PHOSPHORUS LOAD FROM GRASSLANDS TO INLAND WATERS IN SMALL AGRICULTURAL CATCHMENT IN CENTRAL FINLAND BY CONTINUOUS MONITORING SYSTEM

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In surface runoff from grasslands, the main part of total phosphorus (P) is transported in dissolved rather than particulate form. Although grasslands constitute approximately one third of the cultivated area in Finland, there are relative few studies of nutrient losses from grasslands to inland waters. To study the dynamics and amount of P loss from grasslands, we implemented a small catchment-scale continuous monitoring system in 2010. Water quality and discharge is monitored at five sites along the different streams, including various types of land uses (from field-% 100 to forest-% almost 100).

A 3.0 km² sub-catchment of the lake Kirmanjärvi is situated in central Finland. Of this study area, fields accounted for 32%, forests 50% and peatlands 18%. In the coniferous forest, the prevailing soil type is moraine, but the cultivated fields have also a fine texture. The most of the fields are under grass and cereals. Because of the large proportion of dissolved P, water samples are taken using an automated programmable sampler, and analysed for e.g. total P, dissolved P (PO₄-P; Ø 0.2 µm), total suspended solids, dissolved organic carbon (DOC), total nitrogen (N), ammonium-N and nitrate-N. The discharge is monitored with an ultrasonic doppler instrument or through a water level measurement with a pressure probe and a V-notch weir.

During 2011 and 2012, annual precipitation was 690 mm and 800 mm, respectively. The mean annual total P loss for agricultural land was average 1.0 kg/ha/a, being comparable to the results of Vuorenmaa et al. (2002). Whereas in terms of the total P losses from the forested catchments, water coming from the forested study area contained high concentration of P, constituting 0.4 kg/ha/a, and being associated with the point source P load. At the lowest monitoring site, from 8% to even up 93% of the total P was in a dissolved form. After winter runoff started under snow cover; peaking highly during the spring snowmelt period, being typical for annual water cycle in the boreal zone. Consequently, the critical period for P losses may last only few weeks in spring. Due to large annual hydrological variation, the reliable estimates of loading are only achieved by long-term monitoring.

Vuorenmaa, J. et al. 2002. Environ. Monit. Assess. 76: 213-248.

EFFICIENCY OF FERRIC AND ALUMINIUM SULPHATE IN REDUCING P LOAD FROM HIGH SOIL P-STATUS GRASSLAND TESTED ON A SURFACE RUNOFF SIMULATOR (SIMU)

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In Finland most of the grass production is located on areas with severe winter conditions and over 80% of the runoff occurs during snow melt in spring. Freezing and thawing cycles extract P from soil and above ground vegetation. There is a need to prevent P losses from grassland and phosphorus binding chemicals may provide one solution (Uusi-Kämpä et al. 2012). The purpose of this work was to compare the potential of P binding chemicals ferric sulphate ($\text{Fe}_2(\text{SO}_4)_3 \cdot n\text{H}_2\text{O}$) and aluminium sulphate ($\text{Al}_2(\text{SO}_4)_3$) in reducing P load from high soil P-status grassland. The work was committed with surface runoff simulator SIMU (Saarijärvi & Virkajärvi 2010). The amendments (50 mg/m² Ferix-3 or ALG) were applied in early autumn 2010 in four replicates (soil PAC 51 mg-l) The grass mats (0.33 x 0.90 m, thickness 5 cm) were lifted at late autumn 2010 and 2011 and stored in outside temperature until the beginning of the experiment, when the frozen grass mats were placed on the SIMU devices and covered with 30 kg/plot of snow. Infrared heaters melted the snow during 7 days and the meltwater was collected. The process (freezing, snow pack and melting) was repeated three times. Both chemicals decreased the concentration of dissolved P during the first year but not in the following year (Table 1). In the first year the reduction was similar in all periods even though the concentration of dissolved P was low during the second period in all treatments. In contrast, in the second year the concentration of dissolved P decreased in each period. In conclusion, the Ferix-3 and ALG are useful in reducing P load high soil P areas. This is well in line with the results of Uusi-Kämpä et al. (2012). However the effect seems to be short lived. The SIMU device is a suitable method for comparing soil amendments on grassland.

Table 1. The effect of soil amendments on the dissolved P concentrations in surface runoff water

Melting Period	Dissolved P mg L ⁻¹					P-values	
	Control	ALG ¹	Ferix-3 ²	SE	tr	Period	tr*period
2010	1	0.49	0.21	0.04	0.001	<0.001	0.006
	2	0.14	0.04				
	3	0.27	0.11				
2011	1	0.46	0.49	0.07	0.42	0.01	0.67
	2	0.40	0.41				
	3	0.39	0.30				

¹ KemWater™, ALG ² KemWater™, Ferix-3

Saarijärvi, K. & Virkajärvi, P. 2010. 23rd Meeting of EGF, Kiel. p. 78-80. Uusi-Kämpä, J. et al. 2012. JEQ 2012 41: 2: 420-426

THE FIELD SCALE PHOSPHORUS LEACHING MODEL ICECREAM IMPROVES THE WATER QUALITY SIMULATION OF THE FINLAND-WIDE VEMALA MODELING SYSTEM

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Water quality measurements are expensive and time-consuming, and therefore it is not possible to measure water quality from all rivers and lakes. Modeling is a cost-effective method for estimating the phosphorus (P) loading when sufficient measurements are lacking. In this work the field scale, process based P loading model ICECREAM (Jaakkola et al. 2012) was coupled with the Finland-wide water quality model VEMALA (Huttunen et al., submitted). Some equations of ICECREAM were revised to statistically represent the Finnish fields. The results were compared with measurements from Finnish rivers and the earlier version of VEMALA, which calculates the annual agricultural TP load according to the nutrient load assessment tool VIHMA. The daily calculation is based on runoff-concentration relationship and calibration. The different versions are here referred to as V1 (earlier version) and V2 (ICECREAM version). In large areas, both model versions perform fairly well. However, calibration causes sometimes unrealistic concentration patterns in the version V1, especially in small areas. Thus in rivers and lakes, where measurements are scarce or not available, version V2 can be considered more reliable than version V1 (Fig. 1a and 1b). Still, version V2 fails to simulate the P concentrations in the Ostrobothnian catchments in Western Finland. In this area, much of the loading is originated from peat soils, which have a different P loading dynamics than mineral soils. Further development of ICECREAM for peat soil simulations is required.

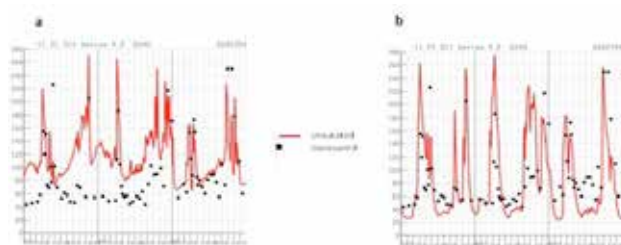


Figure 1. TP concentration ($\mu\text{g L}^{-1}$) in river Vantaanjoki in 2010-2012 simulated with versions V1 (a) and V2 (b).

Jaakkola, E., Tattari, S., Ekholm, P., Pietola, L., Posch, M. & Bärlund, I. 2012. Simulated effects of gypsum amendment on phosphorus losses from agricultural soils. *Agricultural and Food Science* 21:292-306.

Huttunen, I., Huttunen, M., Seppänen, V., Korppoo, M., Lepistö, A., Räike, A., Tattari, S. & Vehviläinen, B. (submitted) 2013. A national scale nutrient loading model for Finnish watersheds – VEMALA. *Environmental Modeling and Assessment*.

THE EFFECT OF SOIL FERTILITY LEVELS AND NITROGEN, PHOSPHORUS AND LIME APPLICATION RATES ON HERBAGE PRODUCTION AND HERBAGE PHOSPHORUS CONTENT

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Phosphorus (P) fertilizer use and soil P fertility levels have been declining in Ireland in recent years. As a result there is now increased emphasis on increasing the efficiency of P fertilizer use. This experiment was established to investigate the effects of additions of nitrogen (N), P and lime on herbage dry matter production and herbage P content over a two year period.

Experimental plots (1.5 m × 6 m) were established on a newly reseeded perennial ryegrass sward at two locations in June 2011. Site 1 had a mean Morgan P in soil of 4.83 mg L and a soil pH of 5.39. Site 2 had a mean Morgan P in soil of 14.92 mg L and a soil pH of 6.17. The experiment was conducted as a 4 × 3 × 2 factorial experiment in a randomised block design with four replicates per treatment. Four rates of P fertilizer (0, 20, 40 and 60 kg ha⁻¹ yr⁻¹; triple super phosphate) were applied at the start of the each year. Nitrogen fertilizer (calcium ammonium nitrate) was applied after each grass harvest from February to mid-September to give annual rates of 0, 150 and 300 kg ha⁻¹ yr⁻¹. Two rates of lime (0 and 5 t ha⁻¹) were applied at the start of the experiment. After establishment, plots were harvested with self propelled lawnmower every 4-5 week during the grass growing season over the following two years. Harvested herbage was sampled and analysed for DM and P content. Soil samples were taken at the start of the trial and at the end of each growing season and were analysed for Morgan P and soil pH.

The results presented are based on 12 harvests over two growing seasons. Nitrogen had a significant positive effect on herbage production at both sites. At both sites there was no additional increase in herbage production from applying more than 20 kg P ha⁻¹ yr⁻¹. Herbage P content was consistently increased by the addition of P fertilizer at both sites. Lime significantly increased the herbage production and decreased herbage P content at site 1, but had no effect at site 2.

The herbage production response to P and lime application was expected at site 1 which had the lower Morgans P and soil pH. However, the herbage production response to P at site 2 was not expected based on existing advice in Ireland and work is continuing to further understand this result.

PHOSPHATE DESORBED FROM ANIONIC EXCHANGE MEMBRANES OVER WINTER AS AFFECTED BY TILLAGE AND FERTILIZATIONZiadi N.¹, Shi Y.¹ and Lalonde R.¹¹Agriculture and Agri-Food Canada, Soils and Crops Research and Development Centre, Quebec, Canada

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Projected global warming may result in large climatic conditions variations including soil temperatures and the number of soil freezing and thawing cycles during winter in cool temperate and high-latitude regions. Determining how agricultural management practices affect changes of soil phosphorus (P) over winter could further our understanding of soil P cycle. Anionic exchange membranes (AEMs) have been successfully used to estimate the availability of soil P in farming systems. The main objective of this study was to assess the effects of tillage systems, mineral N and P fertilization on PO₄-P accumulation on AEMs (AEM-P) over winter. The AEMs were buried in the surface horizon (0-15 cm) over winter (mid-Nov to mid-April) in three consecutive years (2009/2010, 2010/2011 and 2011/2012 in a long-term corn-soybean rotation experiment established since 1992 in eastern Canada. Treatments consisted of two tillage systems including moldboard plow (MP) and no till (NT) and nine combination of fertilization application including three N rates (0, 80, 160 kg N ha⁻¹) and three P rates (0, 17.5 and 35 kg P ha⁻¹) in a split plot design with four replications. Results show that AEM-P was significantly greater under NT than MP across all N and P treatments and years. The AEM-P increased by increasing P application under NT in all the three winters, while AEM-P was greater with no N applied than with N applied under NT in winters of 2010/2011 and 2011/2012. No significant change was observed on AEM-P under MP. We conclude that the fertilized NT had a greater potential for sustaining production in next season and also for P loss via surface runoff in early spring.

GOVERNANCE CONTEXT OF PHOSPHORUS MANAGEMENT IN THE BASIN OF NEMAN IN BELARUS - INSTITUTIONAL BARRIERS TO TECHNOLOGICAL AND BEHAVIORAL INNOVATION IN AGRICULTURAL BMPS AND LOCAL WASTEWATER TREATMENT

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Reduction of phosphorus losses from agricultural systems is a main environmental objective in Nordic countries. This issue involves actors coming across the sectoral and administrative boundaries, and while in the EU the orchestration of the “phosphorus governance” regime became a subject of research scrutiny (e.g. *Larsson & Granstedt 2010*), Russia and Belarus are rarely covered by the international literature, although large portions of the Baltic Sea basin are held by these countries. Belarus is particularly problematic, because it does not participate in HELCOM and is not active in the EU transboundary initiatives. In this study we offer an in-depth analysis of the governance context in which actors and institutions of “phosphorus governance” in Belarus create a combined action resulting in actual P losses. In particular, the paper focuses on the basin on Neman river in Belarus (without the basin of Vilia).

To understand how the socio-political dynamics of the society transforms to management actions, we have reviewed the system of authoritative actors, and made an inventory of institutional misfits and interplays, overlaps and barriers impairing technological and behavioral innovations leading to balanced use, retention and recycling of phosphorus in agriculture in the case study area. Building on outcomes of two stakeholder workshops run under the UNDP project 00079039 “Management of the Niemen River basin...” and 26 semi-structured interviews, we have identified and mapped the main stakeholders in respect to their position on BMPs for P-efficient manure and cropping systems, long-term P removal by wastewater filtration systems (such as *Renman & Renman 2010*), and artificial wetlands. The misfits, overlaps and barriers were analysed in the context of adaptive governance (*Dietz et al 2003*). This was helped by network analysis of actors and institutions performed in NetDraw and Cytoscape.

The study demonstrated that although the political will on the national level is strong, it is in the state of institutional interplay with agricultural policies, which are “pro” intensive crop and livestock production and generally not supportive to more sustainable agriculture. Local wastewater filtration systems and artificial wetlands need to be better communicated to national level decision makers before they can be offered to local communities.

EFFICIENCY OF PHOSPHORUS UPTAKE BY WHEAT CULTIVARS ASSESSED BY THE 32P DILUTION TECHNIQUE

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Brazil is one of the top three importers of wheat (*Triticum aestivum*), due the small domestic acreage (around 2 million ha) and low production (5.78 Mt). Low phosphorus (P) availability is a primary constraint to plant yield in Brazilian soil, so it is necessary to apply large quantities of P fertiliser. However, use of soluble P fertilisers in low input farming in Brazil is limited due to the high cost, while use of unprocessed phosphate rock (PR) as fertiliser usually does not give promising results on annual crop yield. The availability of P from PR can be improved if it is applied to soil mixed with a water-soluble P source (superphosphate). Furthermore, using wheat genotypes able to mine P from PR could be better agronomic practice for improving grain yield in low input farming. It is known that cultivar selection has a major impact on fertiliser requirements, so identifying cultivars with greater ability to grow in soil fertilised with a poorly soluble source of P would be an alternative to reach satisfactory yields.

Using a 32P isotope technique, this study evaluated the P uptake ability of 42 cultivars of wheat grown in soil fertilised with poorly soluble PR, mixed with a water-soluble source of P. The experiment was conducted in the greenhouse in a completely randomised design, with three replicates, in plastic pots holding 2.5 kg air-dried soil taken from the top layer of a dystrophic Typic Haplustox. Each pot received the equivalent of 20 mg kg⁻¹ triple superphosphate (source of readily available P) and 150 mg kg⁻¹ PR. Seedlings were harvested 40 days after sowing and shoot dry matter (SDM) and P uptake (L value) were determined. The results were compared using T-tests at $\alpha=0.05$. There was great variability in growth and P uptake among the 42 wheat cultivars, with average SDM and L value of 0.64 g and 8.18 mg kg⁻¹ soil, respectively. Ten cultivars (IPR 136, BRS 254, CD 116, BRS 264, IPR 130, Caturara, Pardela, IPR 118, IPR 144, IPR 128) presented higher values of SDM and L value (mean 1.00 g and 9.99 mg kg⁻¹ soil for SDM and L value, respectively) and were classified as more efficient in P uptake. These cultivars could provide economic benefits for farmers and could be important in developing future nutrient-efficient cultivars due to their ability to access poorly soluble P.

A PHOSPHORUS BALANCE FOR FIELDS AND WATERSHEDS IN THE ST. JOSEPH RIVER WATERSHED, USA

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Lake Erie holds the most productive fishery in the Great Lakes; however recent increases in the soluble phosphorus loading from agriculture have been implicated in harmful algal blooms (HABs) that have reduced the productivity of this vital resource. In order to reduce phosphorus loading to Lake Erie, we must first understand the phosphorus inputs and outputs in the region. Fields and watersheds in the St. Joseph River watershed have been monitored since 2002. Phosphorus applications to fields range from 0 to 51 kg P/ha. Grain yield is the primary P loss pathway from these fields. The secondary P loss pathway is through runoff and leaching. While these pathways together only transport 0.2 to 2.2 kg/ha to the drainage network, roughly only 1.1 kg P/ha is sufficient to induce the HABs. In some years, the P loads in fields exceed the P loads observed in nested watersheds (~300 – 19,000 ha), while in other years, the P loads from the watersheds exceed what is observed from the fields. Data from source tracking of sediments indicates that more than 50% of sediments transported during runoff events in this watershed are from channel sources, as opposed to upland (i.e. field) sources. This suggests a great deal of in-channel storage of sediments, and thus phosphorus. In conclusion, while phosphorus loads from fields can often exceed the amount of P required to induce HABs, there is also a tremendous amount of storage throughout the landscape. Therefore, the entire landscape needs to be treated as a unit to decrease phosphorus loadings enough to reduce the size of the HABs in Lake Erie.

HALVING OF P LOSSES AFTER IMPLEMENTATION OF MITIGATION MEASURES IN A SMALL AGRICULTURAL CATCHMENT IN SWEDEN

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Losses of phosphorous (P) were studied in a Swedish agricultural catchment dominated by heavy clay soils. The study was run within the project 'Focus on Phosphorous' where farmers, agricultural advisers, researchers and authorities have cooperated since 2007 in order to find and implement effective strategies to reduce P losses from agricultural land to water. Surface water sampling has been performed every fortnight at the stream outlet of the catchment since 1994. Both total and dissolved forms of P have been analyzed in the water samples. Several changes in agricultural practices were implemented in the area during 2009-2010. In the spring of 2009 sediment and vegetation were removed from the mainstream in order to improve soil drainage. In the year 2010, 7 % of the total arable land was converted into buffer zones (6, 12 and 20 m wide) and autumn tillage of arable land decreased from 7 % in 2009 to 2 % in 2010. Further-more, in summer and fall of 2010 about 90 % of the arable land was structure limed with 4 ton lime ha⁻¹ corresponding to 0.8 ton Ca(OH)₂/ha. It was found that the annual total P load in the catchment was approximately halved in subsequent years after the changes in agricultural practices in 2009-2010, compared to the long term average. During the period 1994-2009 the mean annual total P load was 0.78 kg ha⁻¹, but in 2010, 2011 and 2012 annual P loads had decreased to 0.48 kg ha⁻¹, 0.34 kg ha⁻¹ and 0.40 kg ha⁻¹ respectively. As mean annual water discharge was quite large in 2010-2012 (273 mm year⁻¹) compared to the long term average for 1994-2009 (243 mm year⁻¹), the decreased annual P loads in recent years were not caused by a decrease in water discharge, but by significantly lower observed P concentrations in the stream water during 2010-2012 compared to previous years. Similar results were shown for both PO₄-P and particulate P. The results indicate that the measures implemented in the catchment in 2009 and 2010 had a profound effect on P leaching, although the effect of each measure could not be determined separately in this study.

ALTERNATIVE SOURCES OF PHOSPHORUS FOR SOILS: ASSESSMENT OF P FORMS AND USAGE CONSTRAINTS

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Sustainable phosphorus use requires coupling agronomic P inputs with P-rich waste streams. Improved use of recycled P sources is one of the key challenges alongside erosion control, precision fertilizer application and better crop acquisition of a wider range of soil P forms. I examined phosphorus geochemistry of seven soil amendments: sewage sludge, anaerobic digestate (AD), green and foodwaste compost, chicken manure, biochar and seaweed. The aims were to address several issues governing P crop availability and environmental risks such as P leaching. Materials were extracted using NaOH-EDTA and P forms determined using ³¹P NMR. Total P contents ranged between 39 (biochar) to 20231 (sewage sludge) mgP kg⁻¹ dry mass. NMR showed that sewage, AD and composts had >90% inorganic orthophosphate P complexed P by mass, whereas seaweed and chicken manure had greater organically-complexed P (principally monoesters). In terms of crop nutrient acquisition the inorganic P would be more bioavailable dependent on sorption interactions with soil surfaces. For chicken manure and seaweed utilizing greater amounts of this P resource necessitates appropriate crop enzyme strategies to enable P uptake. Water extractions of sludge, AD, compost and manure (100g:1L of 1mM NaCl) had 0.9, 4.4, 1.7 and 7.3 mg L⁻¹ of soluble reactive P (SRP) and 1.3, 19.8, 1.7 and 28.2 mg L⁻¹ of total dissolved P (TDP), respectively. So P solubility in water differed in relation to source P contents and compositions. I used column sorption experiments to examine interactions of water extractable P with a strongly P sorbing soil. After ~60 column pore volumes of leaching (and attainment of C/C₀=1 for all but compost) the soil had retained 11, 94, 31 and 73% of applied SRP and 54, 2, 56 and 1% of TDP in sludge, AD, compost and manure solutions, respectively. So sewage had low P solubility, compost had an SRP leaching risk, but from AD and manure SRP was strongly sorbed but large amounts of TP leached. Back extractions of the sorbed P (without soil drying) with water or citrate (50μM) showed SRP recoveries <1%, indicating difficulties for plant uptake. These data indicate that large variation in P forms and environmental behaviour should be accounted for to maximize the P usage and minimize aspects of leaching and soil P accumulation.

SOIL SUSCEPTIBILITY TO P LOSSES BY LEACHING: FROM GEOCHEMISTRY TO WORKING WITH FARMERS

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As well as losses via erosion P may be leached from certain soils where: (i) soil properties make them of inherent low P sorption status and (ii) management comprises high P inputs in fertilisers. The understanding needed to evaluate such risks comes fundamentally through better appreciation of geochemical principals of P sorption. These are necessary to understand processes behind inherent soil properties determining which soils will have low P sorption and risks of P leaching. However, there are difficulties of addressing the link between soils and P solubility due to the nature of available data, in relation to choices of the best indicators of P status, P solubility and batch conditions. Solubility to waters is generally assessed in laboratory extractions and seldom are such relationships examined in the field. We review soil geochemical understanding gained from soil extractions using data from a focus catchment in NE Scotland (Lunan).

The applications of such knowledge in better P management has dual aims of reducing P pollution to waters and increasing agronomic system P efficiencies by encouraging P inputs to be judged according to crop requirements, but also the limitations of soil properties so that naturally 'P leaky' soils are appropriately managed. P leached from the root zone makes little business sense in farming. Our approach utilise soil geochemical datasets to increase process understanding but importantly this is being combined with a farmer-led soil and drainflow P sampling and awareness campaign. The goal of this is twofold and inter-related, namely that (a) farmers gain awareness of how certain soils should be more appropriately managed to minimise P losses by volunteering and taking part in sampling themselves, then receiving interpreted advisory information, but also that (b) scientific understanding is improved by better data sharing with farmers participating to generate results.

LONG-TERM TRENDS IN PHOSPHORUS LEACHING FOLLOWING PHOSPHORUS FERTILIZATION DRAWDOWN

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The risk of phosphorus (P) leaching from the topsoil has been demonstrated to increase with increasing P content measured as ammonium lactate extractable P (P-AL). Few mitigation strategies are effective for soils with high soil test P and high leaching losses. Extraction of soil P by crop harvesting without P fertilization has been suggested as a method to reduce the risk of P leaching. According to Swedish recommendations, only a limited number of crops should be fertilized with P when grown on soils with high P-AL values ($>120 \text{ mg kg}^{-1}$), and then at moderate rates.

The aim of this study was to investigate if absence of P fertilization in combination with crop harvesting, could reduce P-AL over time, and thereby reduce P leaching. Lysimeters (1.18 m deep) representing four different soil types (loamy sand, sandy loam, silty clay loam and clay), with initial P-AL values between 77-431 mg kg^{-1} , were used. The loamy sand, which had the highest P-AL value, received no P during 11 years and the others during 9 years. Phosphorus removal with harvested products declined during the study, although P-AL remained high and nitrogen and potassium were applied to the soil columns during the last years of the study. The reductions in P-AL were 11-37% between start and end of the experiment, with the smallest percentage change in the soil with highest P-AL and longest time without P fertilization. A decreasing trend in DRP concentration in leachate was found for only one soil, the clay soil with the lowest initial P-AL value of 77 mg kg^{-1} .

Mining P reserves in the soil by crop harvesting and absence of P fertilization, to reduce P leaching losses, seems to be a slow process under Swedish conditions. The results highlight the importance of not over-fertilizing, to avoid high P-AL levels.

PHOSPHORUS TRANSPORT FROM SEPTIC DRAINFIELDS TO GROUNDWATER

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Wastewater contains abundant phosphorus (P) in addition to other contaminants. The contribution of septic systems to groundwater pollution remains largely unknown in most drainage basins in the world. The goal of this presentation is to discuss the fate and transport of P in onsite wastewater treatment system (OWTS, commonly called septic system). We constructed three OWTS; two typical systems (drip dispersal, gravel trench) and an advanced system (primarily to remove nitrogen). Soilwater samples were collected from the vadose zone using suction cup lysimeters and groundwater samples were collected using piezometers. Collected samples (wastewater, soil-water, groundwater) were analyzed for pH, EC, chloride, and various forms of P.

Mean total P in the wastewater was ~10 mg/L, while total P in the lysimeters (0.046-1.72 mg/L) and piezometers (0.01-0.78 mg/L) was much lower indicating enhanced P attenuation in the vadose zone of all OWTS. Most of the reactive P i.e. dissolved reactive P (DRP) was attenuated in the first 1-ft of drainfield, but organic P moved vertically to groundwater.

GRASS CUTTING DATE AFFECTS PHOSPHORUS RELEASE TO RUNOFF FROM FROZEN AND THAWED REGROWTH

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Losses of total P (TP) and dissolved reactive P (DRP) to spring runoff from grassed fields can be high in cold climate due to DRP leaching from plant cells after they have been disrupted by frost. We studied in laboratory if these losses could be potentially diminished by regulating the cutting date and thus the age of regrowth that will overwinter and is on the ground for the following spring.

Regrowth stands were sampled on 26 September 2011, after the unfertilized grass plots had been mowed either on 22 June, 5 July or 1 August (the age of sampled grass was 96, 83, 56 days, respectively). The samples (10 g w.w.) were stored as frozen (−24 °C) for 5 to 6 months after that they were let to thaw in cool (5 °C) over night. The thawed samples were leached with deionized water in cool room (5 °C) and the concentrations of TP and DRP were determined in the leachates. The original plant samples were again refrozen for a week, thawed and leached again. These freeze-thaw-leach cycles were repeated altogether 4 times.

The concentrations of DRP and TP in the leachates of the regrowth biomass were the highest after the first freezing and thawing (Fig. 1a–b). Although the regrowth biomass of the stands mown on 1 August released up to 2.84 mg g^{−1} TP (Fig. 1a) the highest amount of TP (7.4 kg ha^{−1}) was released from the second grass crop grown from 22 June (Fig. 1b) due to its higher biomass per hectare. In fact, 40% and 30% less TP was leached when the first harvest was delayed by 13 or 40 days, respectively, compared to harvest on 22 June. The more aboveground biomass on the field, the more DRP and TP were leached during freezing and thawing events. Almost all of the plant P was leached during the four freeze-thaw events and more than 86% of it was in the soluble form. High release of DRP and TP indicate that leaching of frozen grass by snow melt water can contribute substantial P losses to watercourses in case of several freezing and thawing cycles and associated surface runoff. The loss can be mitigated by delaying the cutting date of the grass stands.

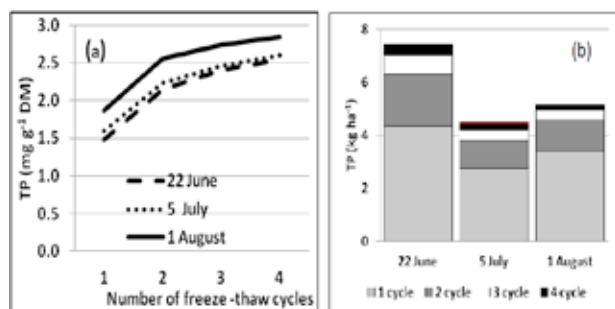


Figure 1. Release of total phosphorus from crop residues after four freezing/thawing cycles.

CHANGES IN SOIL PHOSPHOROUS POOLS ON GRAZED GRASSLAND AFTER 15 YEARS OF MAINTENANCE FERTILIZATION

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Many studies indicate that the availability of phosphate ore is limited. This can affect the agricultural production in the forthcoming decades or centuries. On the other hand the use of phosphorus in intensive agriculture has led to accumulation of phosphorus in soils and losses to surface waters causing eutrophication. Both problems call for a balanced use of phosphate in agriculture. In the Netherlands, the ultimate goal is to reach a balance in P input with fertilizers and P output with agricultural products (maintenance fertilization) by 2015. Farmers fear that this will lead to a decrease in plant available phosphorus and thus to losses of crop yield and crop quality. The aim of this study is to show the consequences of the long term effects of maintenance fertilization on soil P pools. In 1997 a long term (15 yr) experiment was set up to study changes in soil P pools in four grazed grassland sites at P surpluses between 0 and 20 kg P. The sites were located on three major Dutch soil types (noncalcareous sand, marine clay, and peat soils). Soil samples were collected annually at a depth of 0-5, 5-10, 10-20 and 20-30 cm and were analyzed for plant available P (water extractable P (Pw), ammonium lactate extractable P (P-AL), oxalate extractable P (Pox), organic P (Porg) and total-P (Ptot).

Results showed a substantial but not always significant change in plant available P in the upper two soil layers. A significant decline was found at one of the sandy sites and a significant increase in plant available P was found at the clay site. At all sites a significant decline in sorbed mineral P (Pox) in combination with a substantial but not always significant increase in organic P was found. At the clay and peat sites total P increased despite the equilibrium fertilization, which might be explained by the uptake of P from deeper soil layers and an accumulation of P by plant residues in the upper soil compartments. However, the changes in soil P pools in the subsoil were not significant.

Soil layer	location	Annual changes in P pools (kg ha ⁻¹ yr ⁻¹) * = significant				
		Pw	P-AL	Pox	Porg	Ptot
0-5 cm	Sand-AH	-0.2	-5.5*	-8.3*	2.3	-3.5
Sand-Cr		-0.2	-2.3	-4.4*	2.8	6.0
Clay		0.5*	1.2	-2.3	14.5*	14.7*
Peat		0.1	1.0	-1.6	1.6	10.0*
5-10 cm	Sand-AH	-0.2	-3.8	-5.4*	2.9	-4.4
Sand-Cr		-0.2	-1.5	-4.2*	3.6	7.6
Clay		0.5*	7.9*	1.6	18.3*	18.7*
Peat		0.1	0.2	-3.4*	2.2	14.7*

ESTIMATION OF SOIL AND UNREACTIVE PHOSPHORUS LOSSES FROM AGRICULTURAL FIELDS USING A SIMPLE SOIL TEST

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Phosphorus (P) transfer from soil to surface waters is complex and involves different steps from the mobilization of source P to the impact on water bodies, via transport and delivery. The estimation and quantification of particles and P mobilization has proved to be difficult to measure in situ, but is needed to better describe and understand the pathways and processes that soil particles and P follow after their mobilization. In this study, we used an environmental soil test (Withers et al., 2007) to estimate the risk of soil and P mobilization. The results were thereafter combined with high-resolution LiDAR elevation data and crop management information in order to evaluate long-term measurement series of water quality (2000-2011) for five agricultural fields in Central and Southern Sweden, with focus on losses of suspended solids (SS) and different forms of P.

The flow-weighted mean concentrations observed in drainage water during the years 2000-2011 ranged from 0.05 to 0.37 g/l for SS, from 0.12 to 0.39 mg/l for total P, and from 0.08 to 0.33 mg/l for unreactive P. The mobilization risk, measured as turbidity recovered in the aliquot from the soil dispersion test, varied from 781 to 2310 NTU. While the results revealed the efficiency of the environmental soil test in describing and differentiating soil and P mobilization between different fields, they could, however, not be used on their own to describe the losses at the field scale, which showed the importance to include the delivery component. The assessment of simple topographical parameters (slope, length-slope and flow accumulation) based on high resolution LiDAR data, in combination with crop management data, showed how the fields could be described and characterized as either source and transport favored, source limited, or transport limited. The combination of a simple, yet robust environmental soil test to describe soil and P mobilization together with high resolution data and historical field management information to describe sediment and P delivery, makes it possible to explain the long-term observed SS and P losses at the field scale.

Withers, P.J.A., R.A. Hodgkinson, E. Barberis, M. Presta, H. Hartikainen and J. Quinton. 2007. An environmental soil test to estimate the intrinsic risk of sediment and phosphorus mobilization from European soils. Soil Use and Management 23: 57-70.

A COMPARISON OF TWO COMMONLY USED ADVISORY SOIL EXTRACTION METHODS ON A RANGE OF AGRICULTURAL SOIL SAMPLES: IMPLICATIONS FOR FERTILISER P RECOMMENDATIONS AND SYSTEM P USE EFFICIENCY

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Extractable soil P results from Scotland's Rural College (SRUC) commercial laboratory were interrogated for top-soil samples that had been analysed using Modified Morgan's (the standard SRUC method) and Olsen's extractable soil P (commonly used in England and Wales). The results were compared using the appropriate fertiliser index systems highlighted in Sinclair, et al (2010) and Defra (2010) respectively. Since 1996, 234 agricultural top-soil samples have been tested using both methods. The range and frequency at which individual samples matched their soil P status for Modified Morgan extractable P categories with respect to their corresponding Olsen extractable P index are represented in Figure 1. Direct comparison of data clearly shows a wide discrepancy between procedures. The scale and direction of difference was not consistent, although a greater proportion of samples tended to give a higher comparative index for Olsen's P. The discrepancy was particularly wide for the Modified Morgan's group of samples fitting into the High category, with Olsen values varying widely from index 1 through to index 4 (i.e. low through to high P availability). These results highlight the potential to either significantly over or under fertilise crops with P depending on which method is used. It is likely that soil physical and chemical properties are a major influence on the extent to which this might be the case. As a consequence of fertiliser recommendations based on soil analysis which might not be wholly appropriate for the soil under test, the efficiency of P use within the cropping system may be severely compromised.

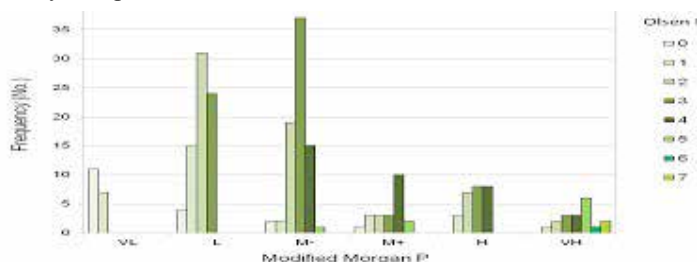


Figure 1. Frequency of soil samples matching Modified Morgan extractable P categories in relation to their theoretically equivalent Olsen P extractable P index.

Defra (2010) Fertiliser Manual (RB209) Version 8.

Sinclair A, Shipway, P & Wale, S (2010) SAC Technical Note TN633: Phosphorus, potassium, sulphur and magnesium recommendations for cereals, oilseed rape and potatoes.

INCREASING THE EFFICIENCY OF PHOSPHORUS IN ARABLE CROP PRODUCTION ACROSS TYPICAL SOIL PHOSPHORUS FERTILITY GRADIENTS IN IRELAND

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Phosphorus is an essential and irreplaceable element for plants and the supply of low cost chemical P fertilizers underpins conventional arable crop production in the developed world. In many regions soil P fertility recommendations for arable crops are to build-up and /or maintain soil test P (STP) concentration at a critical level. In Ireland this is 6 -10 mg L⁻¹ Morgan's extractable P (i.e. P index 3). To maintain this critical STP concentration, crop P off-take must be replenished on P index ≤ 3 soils, and additional P must be applied where soil P index < 2 for build-up. These recommendations are based on results from field experiments, mostly on a limited range of soil types. Different soil types may respond differently to ± P fertiliser balance in terms STP change over time. Rising P fertilizer prices and constrained P use under environmental legislation have led to reduced P fertilizer inputs on Irish farms and an increase in the numbers of soils with sub-optimal STP values (i.e. P index < 3). Farmers and agronomists have become concerned if lower soil P concentrations can be maintained without the risk of declining crop production levels. This study aims to evaluate the P fertilizer recommendations and to investigate the effects of P fertilizer application method on P fertilizer use efficiency in cereal crop production.

Over the 2010 to 2013 cropping seasons P fertilizer response studies were conducted on winter and spring cereals. A range of P fertilizer application rates (0, 10, 20, 30, 40 , 50 , 60 kg ha⁻¹) and methods (surface broadcast (SB), incorporation into seedbed (I) combine drilled with seed (CD)) were evaluated across a range of sites with different soil types and P fertility status. Winter cereal crops were less responsive than spring crops, possibly due to differences in growth habit. Sites with low STP concentrations showed high levels for yield response to P fertilizer addition, but CD produced significantly higher grain yield and crop P recovery than the SB P application method, even at the highest P fertiliser application rates. All sites had low levels of apparent P fertilizer uptake efficiency < 45%. These data indicate that soil test P index system is appropriate for achieving target grain yields, however, the P fertilizer inputs specified may no longer be sustainable or resource efficient for future crop production.

MINIMIZING PHOSPHORUS MOBILITY IN ANIMAL MANURE AND ANIMAL MANURE-IMPACTED SOILS USING BAUXITE RESIDUESWang J.J.¹¹School of Plant, Environmental and Soil Sciences, Louisiana State University, Baton Rouge, LA 70803, U.S.A.

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Animal manures are rich in nutrients and their uses as fertilizer amendment reduce cost for crop production and provides waste disposal for concentrated animal production industry. However, long- term application of animal manures to agricultural lands has caused great concern about the runoff of nutrients such as phosphorus (P) and possible subsequent eutrophication in nearby watersheds. Besides nutrients, animal wastes also contain certain levels of trace metals such as Zn, Cu and As. Various efforts have been made to change the chemistry of nutrients, especially P, of animal manures through pre-treatment before land application. Other efforts are also being considered to immobilize nutrients in manure-affected soils. In this study, we tested the possibility of using bauxite residue, a Fe/Al-rich and Ca-rich by product from aluminum refinery industry, for reducing the leaching potential of P and trace metals from animal manures and manure-affected high-P soils. Fresh poultry litter (PL) and cattle manure (CL) samples as well as poultry litter-affected soils were collected and were subjected to treatment with two bauxite residues, red mud and brown mud. The results showed that both types of bauxite residues reduced water-extractable P from PL and CM but the brown mud treatment yielded higher water-extractable P reduction than the red mud. The higher reduction in soluble P by the Ca-dominant brown mud is likely due to its high sorption capacity over the Fe/Al- dominant red mud. The various bauxite residue amendments reduced water-extractable P by 40-70% in animal manures and by 58-95% in manure-affected soils. Bauxite residues also reduced water soluble fraction of heavy metals in animal manures and manure-affected soils with red mud yielded, however, slightly higher reductions of extractable Zn and Cu than brown mud. In addition, bauxite residues reduced fecal coliform bacteria count by more than one order. The bauxite residue-treated soils showed lower biological oxygen demand than those untreated ones due to reduced leachable P and carbon. It was found that high organic nature of animal manures was able to buffer the alkalinity from the bauxite residues, preventing substantial increase in pH of the treated manures. Bauxite residues could be used as a potential amendment for reducing P and other contaminant in animal manures and manure-affected soils.

UNDERSTANDING THE REASONS FOR INCLUSION OF PHOSPHORUS IN US DAIRY RATIONS

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Dairy farmers in the U.S. are faced with the environmental issue of excess phosphorus (P) in soil which can lead to loss of P to surface water and eutrophication. Phosphorus availability from feeds was examined to better understand 1) the forms of P (organic, phytate and inorganic) in feed and digesta and their subsequent availability and digestion in the dairy cow; and 2) the economics of ration formulation and P concentration in the diet. Ruminal and post ruminal P availability was determined in six ruminally and ileally cannulated cows when dietary phytate (Pp) was fed in diets at low, medium or high (0.10, 0.18, 0.29% DM) and high inorganic P diet (Pi, 0.11% phytate). Total dietary P was 0.43, 0.48, 0.54 and 0.53% respectively. The rumen was the primary site for Pp hydrolysis, and Pp disappearance increased with increasing dietary Pp. Dietary Pp and Pi had no effect on omasal flow of P or degradation of Pp in large intestine. On average, 16% of the ileal Pp flow was degraded and Pi disappearance was observed in the large intestine (8.4, 12.3 and 9.6% of ileal Pi flow for the low, medium and high Pp diets). The dietary P, but not the proportion of P in the form of Pp, affected ruminal and post-ruminal digestion confirms the dominant effect of dietary P content on fecal P excretion. A national survey of P feeding practices documented continued overfeeding of P in the U.S, largely because high P byproduct feeds are widely available as low cost options for dairy rations. Least-cost formulation was used to evaluate the current economic effect of feeding varying dietary P. Using 2013 ingredient prices and balancing for a 705 kg cow producing 36.4 kg milk, with 3.0% protein, 3.6% fat feed costs increased slightly when dietary P was reduced because less high P byproducts were used in the ration. As dietary P increased from 0.35% DM to 0.45%, feed costs decreased (\$6.81 to \$6.78 respectively). This research: 1) confirms the well documented literature that fecal P content increases with an increasing dietary P intake, and 2) demonstrates feeding reduced P diets is more expensive.

ADAPTIVE MODELING OF PHOSPHOROUS REDUCTION TARGETS IN SVÄRTAÅN CATCHMENT

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Phosphorus (P) inputs to Baltic Sea from agriculture must be reduced to improve water quality. In this regard it is important to estimate fulfillment of agreed reduction goals by implementation of known nutrient reduction counter measures, with consideration taken to possible changes in climate and production patterns. In a joint effort within Baltic Compass project, stakeholders from the authorities and water quality modelers developed nutrient reduction scenarios considering possible climate and production changes with 2020 and 2050 as target years. These reduction scenarios include both on-field measures such as structural liming, modified fertilization and spring cultivation practices, and measures in the ditches and streams, such as wetlands and P sedimentation ponds. The study area was Svärtaån river catchment (372 km²) in south-east Sweden.

Several congruent models were used. A field-scale model for calculation of water discharge, erosion and P losses (ICECREAMDB) was implemented within framework of Nutrient Leaching Coefficient Calculation System (NLeCCS) to simulate effects of on-field countermeasures, such as modified fertilization and cultivation practices. The resulting P leaching coefficients were then used as input in FyrisNP source apportionment model to scale-up countermeasure effects on water quality to catchment scale. A new model for cost efficiency, FyrisCOST, was used to calculate the effects of buffer zones in reducing P losses.

The reduction target set as the water framework directive goal was 30% and 38 % lower P concentration at the catchment outlet by 2020 and 2050, respectively. This target was, almost, but not fully, reached when all mitigation strategies were combined. Nitrogen was also simulated within the project and its reduction target of 22% lower load at the outlet, from the Baltic Sea action plan, was reached, but it was very sensitive to the future simulated runoff.

Buffer-zones were not effective due to the limited area where they could be implemented. The most effective phosphorous measures according to model results were structural liming and sedimentation ponds. However, these measures are in model implemented as simple constant reduction factors with high uncertainty. This is too simplistic and further research and model development to account for the effect of nutrient reduction measures is strongly needed.

FROM WASTE DISPOSAL TO SCIENTIFICALLY JUSTIFIED USE OF PHOSPHORUS IN ANIMAL MANURE

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Past agricultural policy in Finland has rarely considered site-dependent nutrient cycles and their influence on the environment. Consequently, livestock production in Finland is most intensive along the coast of the Gulf of Bothnia and the Archipelago Sea, causing an accumulation of manure phosphorus (P) in the cultivated soils. Unbalanced P cycles are further distorted by the use of mineral P fertilizers. To describe the site-specific role of manure P we estimated its contribution as the only P source for cereals and grass at a municipality level for obtaining 95% of the maximum yields. The calculations considered soil test P (STP) values, manure P content in each municipality and the area under cultivation, excluding fallow. Optimum P fertilization rate was calculated for different soil types according to Valkama et al. (2009, 2011).

STP values (P_{aaac}, pH 4.65) obtained from soil testing laboratories (about 1 mill. soil samples during 2005-2009), covered about 95% of the cultivated area in Finland and represented on the average of 2 ha each. Amount of manure P was calculated according to feeding trials done at MTT. Bio-availability of manure P was considered equal to mineral P fertilizers.

Due to the past P fertilization history in Finland, 49% of the soil samples had such a high STP values that no additional P fertilization is required. On the average 8.6 kg P ha⁻¹ is required, whereas P content in animal manure was about 17.5 million kg in year 2011, i.e. 8.8 kg ha⁻¹. Results at the municipality level will be visualized with maps, showing highest surplus of manure P as 169 kg ha⁻¹, and deficit as 15.6 kg ha⁻¹.

Environmental consequences of high STP can be markedly diminished by cutting P applications and using manure as the primary P source. Ideally, at present there would be negligible need for inorganic P fertilizers. Scientifically justified P use would eventually decrease P loads from agriculture to surface waters.

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SOIL PHOSPHORUS LOSSES IN SURFACE RUNOFF AND TILE DRAINAGE AS RELATED TO ORGANIC AMENDMENT ADDITION AND WATER MANAGEMENT

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Understanding phosphorus (P) loss in soils receiving organic amendment under various water management strategies is important to develop risk assessment tools and BMPs that minimize adverse impacts of agricultural practice on water quality. An experiment was conducted in a clay loam soil of Eastern Canada over a 4-year period to determine soil P losses in surface runoff (SR) and tile drainage (TD) as influenced by addition of composts (leaf yard waste - LYW, and liquid swine manure - wheat straw - SMC) under regular drainage (RD) and controlled drainage/sub-irrigation (CDS). Composts were disked in at 75 Mg ha⁻¹ to the corn phase of a corn-soybean rotation. Surface runoff and TD flows were monitored and samples collected continuously year round using an auto-sampling system. Water samples were analysed for total dissolved P (TDP), dissolved reactive (DRP), and particulate P. Under RD, TDP contents in the control plots averaged 0.33 mg P L⁻¹ (range = 0.20-1.12 mg P L⁻¹) in SR, and 0.26 mg P L⁻¹ (range = 0.31-1.67 mg P L⁻¹) in TD. Levels of TDP in SR increased by 77 and 1033% with added LYW and SMC, respectively. In TD, TDP contents increased by 81% with added LYW and by 999% with added SMC. Under CDS, TDP contents in the control plots averaged 0.32 mg P L⁻¹ (range = 0.23-1.34 mg P L⁻¹) in SR, and 0.24 mg P L⁻¹ (range = 0.14-1.52 mg P L⁻¹) in TD. Contents of TDP increased by 78% with LYW and by 1772% with SMC in SR, and in TD by 87% with LYW and by 1741% with SMC. Annual total P losses (ATPL) through both SR and TD were 1818 g P ha⁻¹ in the control plots, and increased to 2169 and 10264 g P ha⁻¹ with added LYW and SMC, respectively, under RD. Under CDS, ATPL was 1748 g P ha⁻¹ in the control plots, and increased to 2124 and 15170 g P ha⁻¹ with added LYW and SMC, respectively. Of the ATPL, from 42 to 81% was attributed to P loss in drainage water. Dissolved reactive P accounted for 30, 43, and 75% of the soil P loss in the control, LYW and SMC treatments, respectively, and the percentages were similar between DR and CDS and between SR and TD. The CDS increased soil P losses through increased surface runoff only when in combination with SWC. Regardless of soil water management, SMC increased substantially soil P losses through both SR and TD. Tile drainage can be a significant pathway for P loss contributing to the eutrophication of water bodies.

CUMULATIVE CONTRIBUTIONS OF VARIOUS FORMS OF SWINE MANURE TO SOIL TEST PHOSPHORUS IN A CLAY LOAM SOIL UNDER LONG-TERM CORN-SOYBEAN ROTATION

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Determination of long-term cumulative trends of manure form-specific effects on soil phosphorus (P) is essential to nutrient management practices and planning that assures maximized use efficiency while minimizing adverse impacts on water quality. A study was conducted to quantify the cumulative changes in soil test P (STP, Olsen-P) as a function of various forms of swine manure (liquid, LM; solid, SM; and liquid swine manure compost, MC); and relative to chemical fertilizer P to determine the manure P source co-efficient in a Brookston clay loam soil under corn-soybean rotation from 2004 to 2011. Manure or chemical fertilizer was applied using a P-based approach at the same rate, 100 kg P ha⁻¹ year⁻¹ to the corn phase only. Post-harvest STP content increased linearly with the year of application in the 0-30 cm depth, while it remained unchanged in the depths below 30 cm. The amount of manure-P needed to increase STP by 1.0 mg P kg⁻¹ was 20, 29 and 24 kg P ha⁻¹ yr⁻¹, respectively, for LM, SM, and MC if only the surface 0-15 cm soil layer was considered. When the subsoil 15-30 cm layer was included, an amount of 16, 22 and 16 kg P ha⁻¹ yr⁻¹ manure-P was required respectively for LM, SM, and MC to increase each mg P kg⁻¹ of STP. By using a net P addition approach that subtracts crop P removal from the total P applied, the amount of manure P required to increase each mg P kg⁻¹ of STP in the 0-30 cm depth were 10, 14 and 11 kg P ha⁻¹ for LM, SM, and MC, respectively. Manure P source coefficients, determined as the equivalency to chemical fertilizer P, were 1.04, 0.98 and 0.93 in the 0-15cm soil depth, and 1.01, 0.96, and 0.94 in the 0-30cm depth for LM, SM, and MC, respectively. Long-term effects of swine manure on STP varied slightly with its forms, but were all similar to chemical fertilizer P under the corn-soybean rotation cropping system.

INDEX

A

Abdi D. 51, 70
Amery F. 71
Andersson H. 72
Andersson L. 104
Andersson S. 67, 146
Appels W.M. 41
Aronsson H. 46, 115
Astrup T. 110
Audette Y. 73
Aurell-Svensson A. 67
Avilés M. 86, 87, 88

B

Bachmann S. 91
Bailey J. 141
Baker-Ismail S. 33
Barbaro L. Alejandra 74
Barrett D. 33
Batelaan O. 36
Bathmann U. 112
Ba Y. 121
Bechmann, M. 38
Bélanger G. 43, 105, 121, 122
Bell G. 33
Beltran M.Javier 74, 75
Bergkvist G. 115
Bergström L. 62, 72, 135, 149, 153
Bhadha J.H. 66
Blackwell M. 28
Blackwell M.S.A. 59, 76
Blazkova S.D. 77
Blombäck K. 158
Bol R. 28, 76
Bolster C.H. 42
Bonvin C. 30
Borggaard O.K. 58, 99
Bouraoui F. 24
Bowes M. 78
Brahana J.V. 34
Brennan R.B. 78
Bruno I.Pereira 144

Brysiewicz A. 128
Buckley C. 79, 124
Bus A. 80

C

Cabral F. 136
Cade-Menun B.J. 33, 51, 90
Camacho M.A. 117
Cambouris A.N. 81
Canga E. 108
Cano Bernal J.E. 130
Carneiro J.P. 100
Chambers P.A. 82
Chardon W.J. 83
Clough T.J. 57
Colinet G. 133
Collentine D. 68
Collins A.L. 59, 76
Condron L. 28
Condron L.M. 57
Corriveau J. 82
Cougnon M. 50
Coull M.C. 116
Coutinho J. 136
Couture R.-M. 84
Crespo D. Elvira 74
Crooks W. 116
Crossman J. 27
Cruzate G. 75
Culp J.M. 82

D

Daly K. 123
Darch T. 59
Daroub S. 66
Del Campillo M.C. 85
Delgado A. 86, 87, 88, 89
Della Torre V. 74
D'Hose T. 50
Diels J. 36
Dixon E.R. 76
Dixon L. 28
Djodjic F. 40, 67, 72, 146, 153

Doody D.G. 90
Duarte A.C. 100
Dubil, M. 128

E

Eckersten H. 158
Edwards A.C. 29, 116, 154
Ehlert P.A.I. 152
Eichler-Löbermann B. 91, 134
Ekholm P. 44, 56, 130
Ekre E. 67
Eriksson A.K. 92
Etana A. 93
Etter B. 30
Evans L.J. 73

F

Fangueiro D. 136
Fiala D. 94
Forsmann D.M. 107
Fouli Y. 33
Franzini V. Ide 144
Frossard E. 30
Futter M. 27

G

Gade A. 137
Gagnon B. 70
Garcia-Lopez A.M. 87, 88
Gąsiorek M. 97, 118
George T. 28
Gil-Sotres F. 95, 96
Govers G. 36
Graça J.I, Fangueiro D. 136
Groenenberg J.E. 83
Gustafsson J. 67, 146
Gustafsson J.P. 92

H

Haggard B. 78
Hanigan M.D. 157
Hansen H.C.B. 58, 99, 108
Hao X. 161
Harris E.M. 57
Harrison J.H. 157
Hauggaard-Nielsen H. 125
Haygarth P. 28

Heckrath G. 98, 108, 137
Heeb A. 67, 104
Heiberg L. 99
Henessy D. 141
Hesterberg D. 92
Hillier S. 92
Hodder K. 33
Hoffmann C.C. 108
Hong J. 161
Horta C. 100
Huang B. 101
Huttunen I. 140
Huttunen M.J. 140
Hyväluoma J. 113

I

Iversen B.V. 98, 108

J

Jaakkola E. 56
Jackson-Blake, L.A. 102
Jakobsen I. 125
James R.E. 157
Jang J.-R. 106
Jarrett J.P. 157
Jarvie H.P. 34, 78
Jate M. 129
Jeangros B. 105
Johannesson K. 111
Johannesson K. M. 103
Johannesson K.M. 104
Johnsson H. 68
Jones D.L. 29
Jordan P. 35, 120, 124
Joseph D. 133
Jouany C. 43, 105

K

Kabbe C. 24
Karczmarczyk A. 80
Karlanian M. Alejandra 74
Kaseva J. 151
Kaste Ø. 84
Kelly-Quinn M. 120
Khalaf R. 115
Kiirikki M. 56
Kim J.-S. 106

Kirchmann H. 72
 Kireyeu V. 143
 Kirjalainen (née Hirvonen) S.S. 56
 Kjaergaard C. 98, 107, 108
 Kleinman P.J.A. 62, 149
 Klimeski A. 54, 109
 Klinglmair M. 110
 Knowlton K.K. 157
 Koopmans G.F. 83
 Korppoo M.T. 140
 Krämer I. 112
 Kristensen K. 137
 Kruse J. 112
 Kulasova A. 77
 Kyllmar K. 67, 146
 Kynkäänniemi P. 103, 111

L

Lafond J. 121
 Lahti K. 56
 Lalande R. 70, 142
 Lalor S. 141
 Lalor S.T.J. 123
 Lammel J. 129
 Lang T. 66
 Larsson P. 68, 158
 Lawlor A.J. 34
 Lee J.-B. 106
 Lee J.-Y. 106
 Lee S.-H. 106
 Lehtoranta J. 44
 Leinweber P. 112
 Leirós C. 95, 96
 Lemola R. 159
 Lepistö A. 131
 Lewis E. 141
 Lilja H.J.S. 113
 Lindström G. 104
 Litaor I. 114
 Liu C.W. 90
 Liu J. 115
 Lumsdon D.G. 116, 148
 Luomanperä S. 56
 Lyngsie G. 58

M

MacKay R. 28

Malgeryd J. 67, 146
 Mallarino A. 75
 Marcante N. 144
 Marcante N.C. 117
 Markensten H. 68, 158
 Martin R.C. 73
 Massop H.T.L. 41
 Matthews R.A. 59, 76
 Mazurek R. 118
 McCall S.J. 119
 McDowell R. 123
 McMartin D.W. 33
 Mechan S. 124
 Mechtensimer S. 150
 Melland A.R. 35, 120, 124
 Mellander P.-E. 35, 120, 124
 Merckx R. 36, 50
 Messiga A.J. 43, 81, 121, 122
 Milver A. 104
 Morel C. 43, 81, 105, 122
 Müller-Stöver D. 125
 Muraoka T. 117, 144
 Murphy P.N.C. 35, 52, 79, 123, 124

N

Nanzer S.A. 30
 Närvänen A. 54, 109
 Nausch M. 126
 Nielsen P. 98
 Niemeläinen O. 151
 Noij I.G.A.M. 41
 Nousiainen J. 159

O

Oberson A. 30
 Oenema, O. 24
 O'Halloran I.P. 73
 Orback C. 158

P

Pakhomau A. 143
 Parent L.-É. 51, 70, 81
 Pavinato P.S. 46, 127
 Penn C. 58
 Perez-Valdivia C. 33
 Persson K. 68
 Pietrzak S. 128

Plunkett M. 155
Prem M. 99
Puustinen M. 113

R

Rangel Becerra A.F. 129
Rankinen K. 130, 131
Rasa K. 54, 109
Ray P.P. 157
Recena R. 86, 89
Reheul D. 50
Renman, A. 132
Renman, G. 132
Renneson M. 133
Requejo M.I. 134
Ribeiro H. 136
Ribeiro P. 100
Richardson A. 28
Richards S. 148
Riddle M.U. 135
Riera N. Ivan 74
Rivero E. 75
Rizzo P. Federico 74
Roboredo M. 100, 136
Rodrigues M. 127
Rodrigues M.D. 117
Roisin C. 133
Ronchi B. 36
Räty M. 138, 139
Rönnberg R. 104
Rubæk G.H. 137
Ruysschaert G. 50

S

Saarijärvi E. 138
Saarijärvi K. 138, 139
Sánchez-Alcalá I. 85
Sarvi M. 159
Scheutz C. 110
Schoumans O. 24
Scott T. 78
Seppänen V.K. 140
Shafei B. 84
Shand C.A. 28, 116, 148
Sharpley A.N. 20, 34, 62, 78, 136
Sheil T. 141
Shine O. 124

Shi Y. 70, 142
Shkaruba A. 143
Shore M. 120
Shortle G. 35, 123, 124
Silva A. 117
Silva A.da 144
Simmons T. 34
Simonsson M. 92
Sims J.T. 52
Sims T.J. 123
Sinaj S. 43, 105
Sinclair A.H. 116
Smith D.R. 65, 145
Stamm C. 32
Starrfelt J. 84
Stewart B. 157
Stjernman Forsberg L. 67, 146
Stroia C. 43, 105
Struyf E. 36
Stutter M.I. 28, 116, 147, 148
Sundin S. 158
Sun W. 101
Suomela R. 43
Svanbäck A. 149
Sylvester-Bradley R. 29

T

Tainio A. 131
Tamburini F. 30
Tan C. 160, 161
Tominaga K. 84
Tonderski K.S. 103, 104, 111
Tong Y. 49
Toor G.S. 150
Torrent J. 85, 100
Trasar-Cepeda M.C. 95, 96
Troitiño F. 95, 96
Turner B. 28
Turtola E. 54, 109, 113, 159

U

Udert K.M. 30
Ulén B. 46, 67, 72, 92, 103, 111, 115, 146, 149
Uusi-Kämppe J. 151
Uusitalo R. 54, 109, 159

V

Vadas P.A. 42
Valkama P. 56
Vandecasteele B. 50, 71
Vanden Nest T. 50
Van der Salm C. 41, 152
Vandevenne F. 36
van Dijk K. 24
Van Gaelen N. 36
Van Middelkoop J.C. 152
Vasconcelos E. 136
Vehviläinen B.V.K. 140
Verheyen D. 36
Villa A. 153
Virkajärvi P. 43, 138, 139
Voroney P.R. 73

W

Wahlström S. 44
Walker R.L. 154
Wall D. 52, 79, 123, 124, 141
Wall D.P. 155
Wang B. 101
Wang J.J. 156
Watson C.J. 90
Welacky T. 160, 161
Wendler R. 116
Wenzel W. 99
Wesołowski P. 128
Whitefield E.M. 157
Whitehead P.G. 27
Widén-Nilsson E. 158
Withers P.J.A. 29, 46, 62, 127
Wu K. 33

Y

Yang Y.-Y. 150
Yli-Heikkilä K. 151
Ylivainio K. 159

Z

Zaleski T. 118
Zhang T. 160, 161
Ziadi N. 43, 51, 70, 81, 105, 121, 122, 142

